March 2021 Textbooks for university students

ERGONOMICS MODIFY CONDITIONS OF WORK and THE SAFETY AT WORK

Assoc. Prof. Ing. Jan KRMELA, Ph.D.

ISBN 978-83-63978-87-7

Publisher: **Oficyna Wydawnicza Stowarzyszenia Menadżerów Jakości i Produkcji**
(Printing House The Managers of Quality and Production Association), Czestochowa, **Poland**

Jan Krmela

ERGONOMICS MODIFY CONDITIONS OF WORK and THE SAFETY AT WORK

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2021, March

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Title: **Ergonomics Modify Conditions of Work and The Safety at Work : Textbooks for university students**

Book type: Textbook for university students **(VŠ učebnice)**

Language: English

First edition. Published in March 2021

Page size: 254 x 190.5 mm, 361 pages, pdf format, electronic version

Publisher: **Oficyna Wydawnicza Stowarzyszenia Menadżerów Jakości i Produkcji** (Printing House The Managers of Quality and Production Association), Czestochowa

Country of publisher: **Poland**

Number of author's sheets: **4.76**, number of standard pages: 95.2

Videos from 3D printing and specific test of composite are included on the enclosed **DVD**.

This textbook has not been checked and corrected for spelling errors.

Series: textbooks for university students available online http://krmela.wz.cz/contact.html.

Reviewers:

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Nadiia ARTYUKHOVA, PhD. (Sumy State University, Sumy, **Ukraine**)

ISBN 978-83-63978-87-7

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This textbook consists of two different but related parts.

The first part „Ergonomics modify conditions of work“ is based on various authors and publications and other sources have been used (see References at pages 12-14). This part was compiled so that the problem of ergonomics was described more comprehensively.

The second part „The safety at work ….“ with a larger text range is only the work and results of the author himself. The part presents work safety in relation to interesting problems from practice.

I believe that this textbook will help university students and students from Wyższa szkoła zarządzania ochroną pracy w Katowicach, Poland and all interest students from anywhere at World to better understand ergonomics and safety at work.

Jan Krmela, the author

About the Author

Since 2013, assoc. professor Jan Krmela (1978) has been the Head of the Department of numerical methods and computational modeling at the Faculty of Industrial Technologies in Púchov at Alexander Dubček University in Trenčín, Slovakia. He received his Ing. degree with honors in the field of study Transport Means – Road Vehicles at Jan Perner Transport Faculty at the University of Pardubice, Czech Republic and a Ph.D. in Transport Means and Infrastructure at the same institution. He habilitated in Transport Means and Infrastructure (the habilitation work "The computational modeling of automobile tires") at the same university in 2010. He is a member of the Association of Mechanical Engineers (A.S.I.), the Czech Society for Mechanics and the Scientific Council at the Faculty of Industrial Technologies in Púchov. In 2006, he received a special award for science and research activities by the Rector of the University of Jan Evangelista Purkyně in Ústí nad Labem, Czech Republic. In 2016, he was awarded the Bronze Medal of Maximilián Hell for the development of the Faculty of Industrial Technologies in Púchov, science and education. At 2020, he received Award for the development and support of science, research and education, Alexander Dubček University of Trenčín.

He has been gaining experience in the FEM program ANSYS since 2000. He co-operated with the Fraunhofer Institut für Techno- und Wirtschaftsmathematik ITWM, Kaiserslautern, Germany and the Kompetenzzentrum - Das Virtuelle Fahrzeug Forschungsgesellschaft mbH, Graz, Austria (long-term stays by programs Erasmus+, DAAD and others stays). In 2016, he delivered lectures at the Belarusian State Technological University in Minsk, Belarus. He has been a supervisor of dissertation thesis; five Ph.D. students successfully finished under his guidance. He received financed projects GAČR, FRVS, KEGA and Erasmus+. He gives lectures, lessons and organizes seminars on technical subjects. The results of his work have been presented at conferences and in technical papers in CC journals, journals, monographs and chapters of books. Jan Krmela authored over 280 publications in the following research areas:

- Computational modeling and tests of composites with a rubber (an elastomer) matrix such as tire casings, especially with focus on strain-stress states and modal analysis and computational modeling of composites after the degradation processes, tire-road interaction and vehicle parts;
- Tests of tires on static and dynamic test machines with the pressure footprint analyses of contact footprints between tires and a plane road or a bump and also prediction of radial stiffness of tires;
- Specific low cyclic loading tests of composites with textiles on a test machine with a video extensometer and static tests of composites with planning of tests with a design of geometric parameters of test samples and test conditions for testing of tire casing parts;
- Determination of material parameters that can be used as input data into computational models;
- Microscopic observation of interface bonds between steel and textile cords and an elastomer;
- Safety at work in experiments of polymers and composites and ergonomic problems;
- 3D printing FFF of technical objects.

LinkedIn and Research Gate: see at the website **http://krmela.wz.cz/contact.html**

ORCID https://orcid.org/0000-0001-9767-9870

Acknowledgments

This research work and this textbook had been financially supported by

the Cultural and Educational Grant Agency of the Slovak Republic (KEGA),

grant No. **KEGA 002TnUAD-4/2019.**

The author especially thanks **dr hab. inż. Robert ULEWICZ, prof. PCz.**

CONTENTS of Textbook

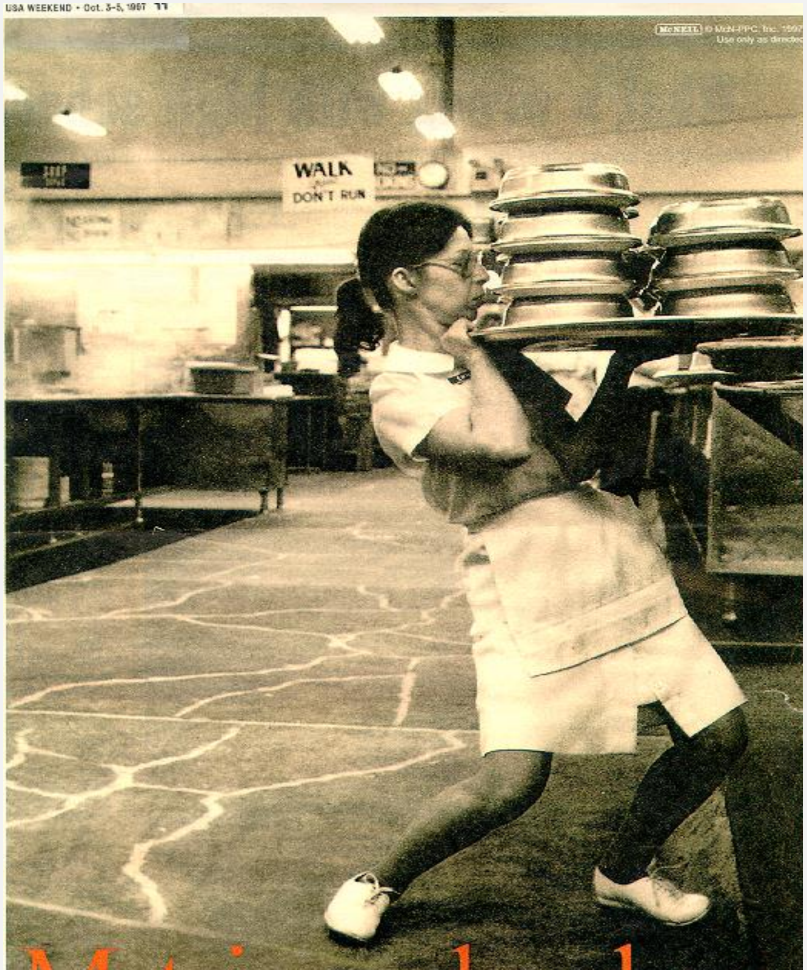
Ergonomics

Ergonomics

What is the pictureS showing us?

What are they proposing as a solution?

What alternative solutions would you suggest?



Introduction

Lesson objectives:

Identify common work-related musculoskeletal disorders (MSDs).

Work-related **M**usculo-**S**keletal **D**isorders (WMSDs)

Recognize risk factors associated with work-related MSDs.

Identify ergonomic control methods for eliminating/reducing work-related MSDs.

- How can I evaluate my workplace?
- What are some ergonomic solutions?
- Introduce ergonomic exercises.

Introduction

Lesson objectives:

- Office Ergonomics
- Industrial Ergonomics

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Introduction

Ergonomics

"The scientific discipline concerned with understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, methods and data to design in order to optimize human well-being and overall system performance"

Ergonomics is the study of designing equipment and devices that fit the human body, its movements, and its cognitive abilities.

Introduction

Ergonomics means
"fitting the job to the worker,"
including:

- Work stations
- Tools
- Equipment

Ergo = Work

Nomos = Law

= **Study of the Laws of Work**

= the "science of work"

- Designing jobs, equipment, and work tasks to fit human physical characteristics and energy limitations
- It considers body dimensions, mobility, and the body’s stress behavior
- “Make the work fit the person, not the person fit the work”
- The word “ergonomics” is from Greek: “ergo” means “work,” and “nomics” means “laws pertaining to.” So ergonomics is “the laws pertaining to work.”

Definition

- ERGONOMICS is a way to work smarter - not harder by designing of tools, equipment, work stations and tasks to fit the job to the worker - NOT the worker to the job:
  - Layout / type of controls and displays
  - Lighting and Temperature
  - Process (Heights, reaches, weights)

The ‘fit’ between people and their work

Definition

- Ergonomics is the science of fitting the job to the worker, matching the physical requirements of the job with the physical capacity of the worker.
- Ergonomics is used to design an environment (layout, work methods, equipment, noise, etc) which is compatible with each individual's physical and behavioral characteristics. Ergonomics looks at the behavior of the person performing the job.

What is Ergonomics?

The main objective is especially fitting with the need to design, develop, implement and evaluate human-machine and environment systems that are productive, comfortable, safe and satisfying to use.

Ergonomics is the scientific study of how people interact effectively with products, equipment, facilities, procedures and environments used at work and in everyday living.

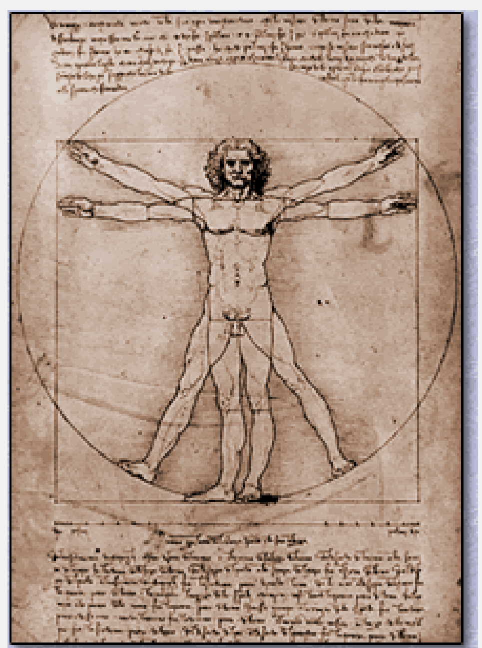
Ergonomics seeks to maximize ease of use and optimize operator productivity, comfort and health.

Ergonomics (or human factors) is the scientific discipline concerned with the **understanding of the interactions among human and other elements of a system**, and the profession that applies theory, principles, data and methods **to design in order to optimize human well-being and overall system performance**.

- Human factors
- The ‘fit’ between people and their work
- Puts people first
- Considers capabilities and limitations

The ‘Fit’ between task and worker

- Task(s) and the demands on the worker
- Equipment used (design, size, fit for purpose)
- Information used (access and content)
- Physical environment
- Social environment (support of colleagues).



Human factors

The body

- Size and shape
- Fitness and strength
- Posture
- Senses
- Stresses and strains

The mind

- Mental ability
- Personality
- Knowledge and experience
- Stresses and strains

Do we consider?

What people do?

What equipment they use?

How they do it?

How often they do it?

Where they do it?

Capability?

Understanding?

Experience?

The route to an appropriate ergonomic assessment is to ask pertinent questions (would a check list be a good aid-mémoir?
These questions can lead us through the process.
The questions to be asked will lead to consideration of individual needs and this forms the core part of step 2 of a risk assessment asking ‘who will be affected?’
Individual capability may be addressed and a sound risk assessment can be achieved, but considerations of individual needs can lead to changes of organisation of the work.

Why is ergonomics important?

- Overexertion leading cause of injuries
  - Most costly
  - Recurring/Persistent pain may develop in future
- Bodily reaction is another leading cause of injuries in workplace
- Repetitive motion also within top 10 most common workplace injuries

Goals of Ergonomics

•Reduce the risk of injury, fatigue, error

• Improve productivity and quality

•Improve quality of worker environment

• Increase profit

• Being proactive, rather than reactive

"The Main Goals"

Minimize injuries
Improve productivity and quality and reduce the risk of musculoskeletal disorders (MSDs) !!!

What do Ergonomists do?

- **Communication** Share ideas with everyone involved (manager, employee, ergonomist)
- **Recognize Potential Risks** Identify possible risks such as forces,awkward postures & repetition
- **Assess the job** Quantitatively & qualitatively
- **Recommend & Justify Changes** Administrative & engineering changes
- **Follow-Up** Evaluate the changes made (success in both short & long term)

Some Areas of Application for Ergonomics

1) Accidents, Health and Safety at Work

2) Office Ergonomics and Design

3) Design and Layout of Displays and Controls

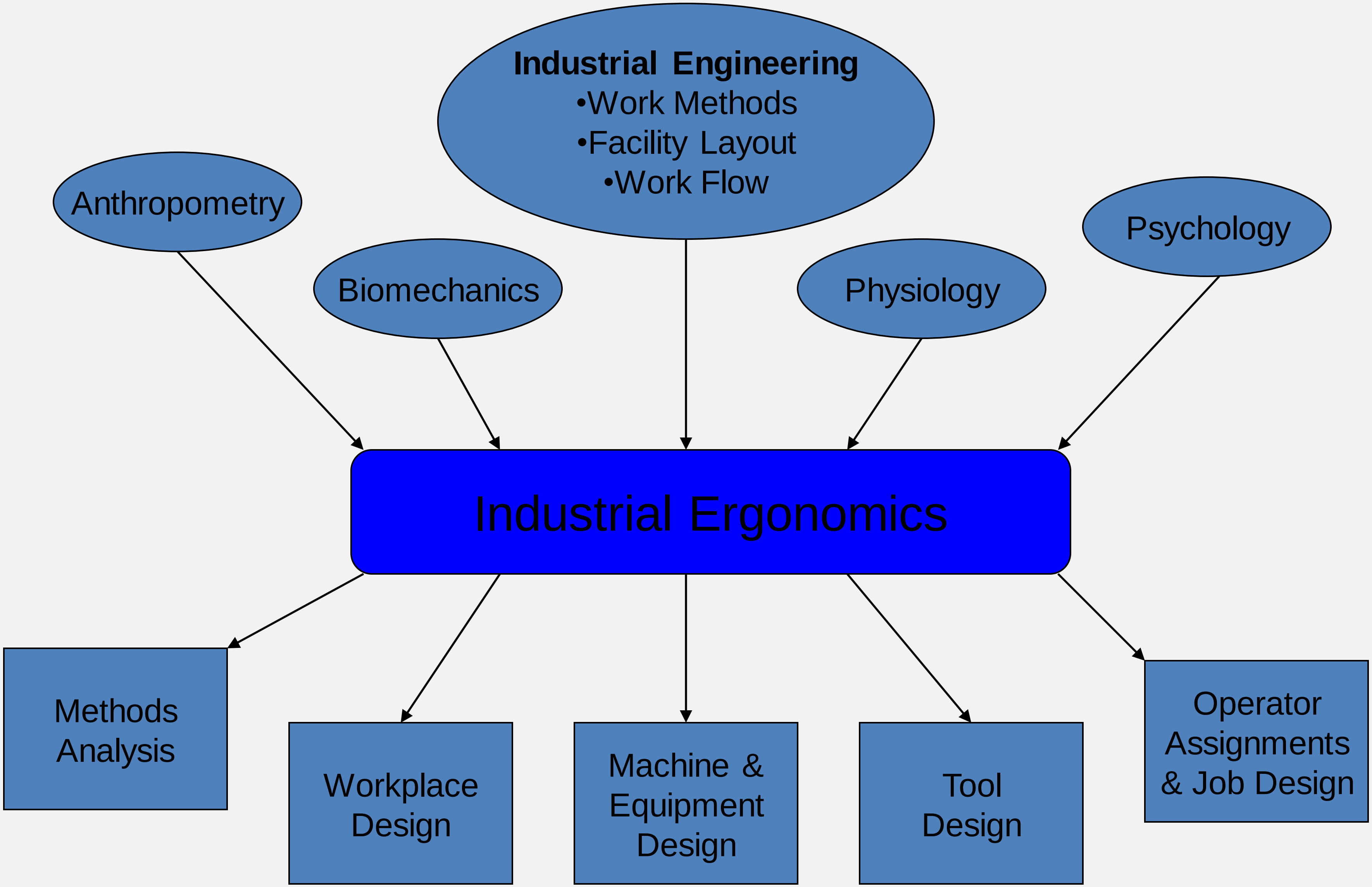
4) Product Design and Consumer Ergonomics

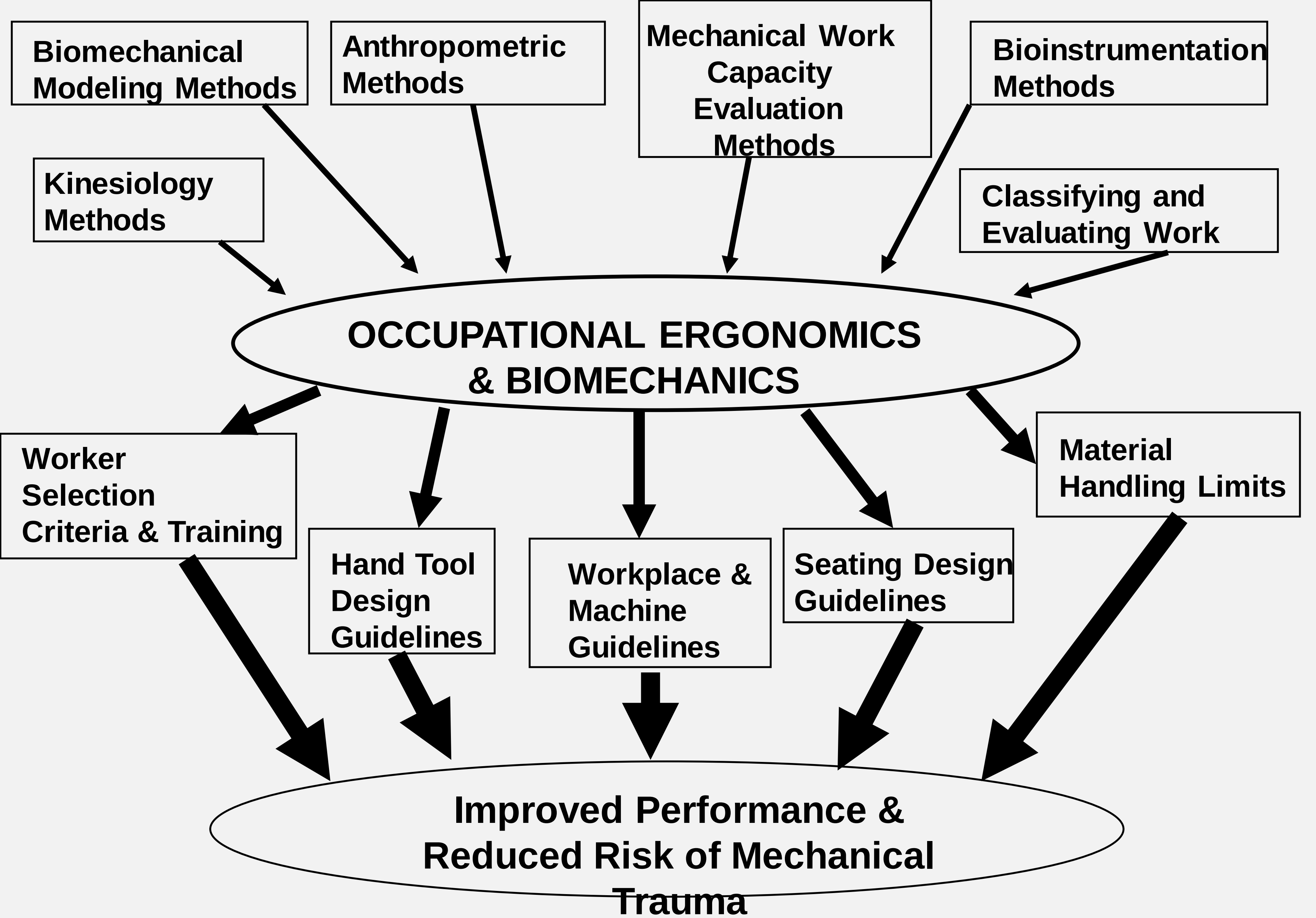
5) Human Reliability

6) Industrial Design Applications

7) Ergonomics Training for Management and Staff

8)Work-related Musculoskeletal Problems


Industrial Engineering
•Work Methods
•Facility Layout
•Work Flow
Anthropometry
Biomechanics
Physiology
Psychology
Industrial Ergonomics
Methods Analysis
Workplace Design
Machine & Equipment Design
Tool Design
Operator Assignments & Job Design

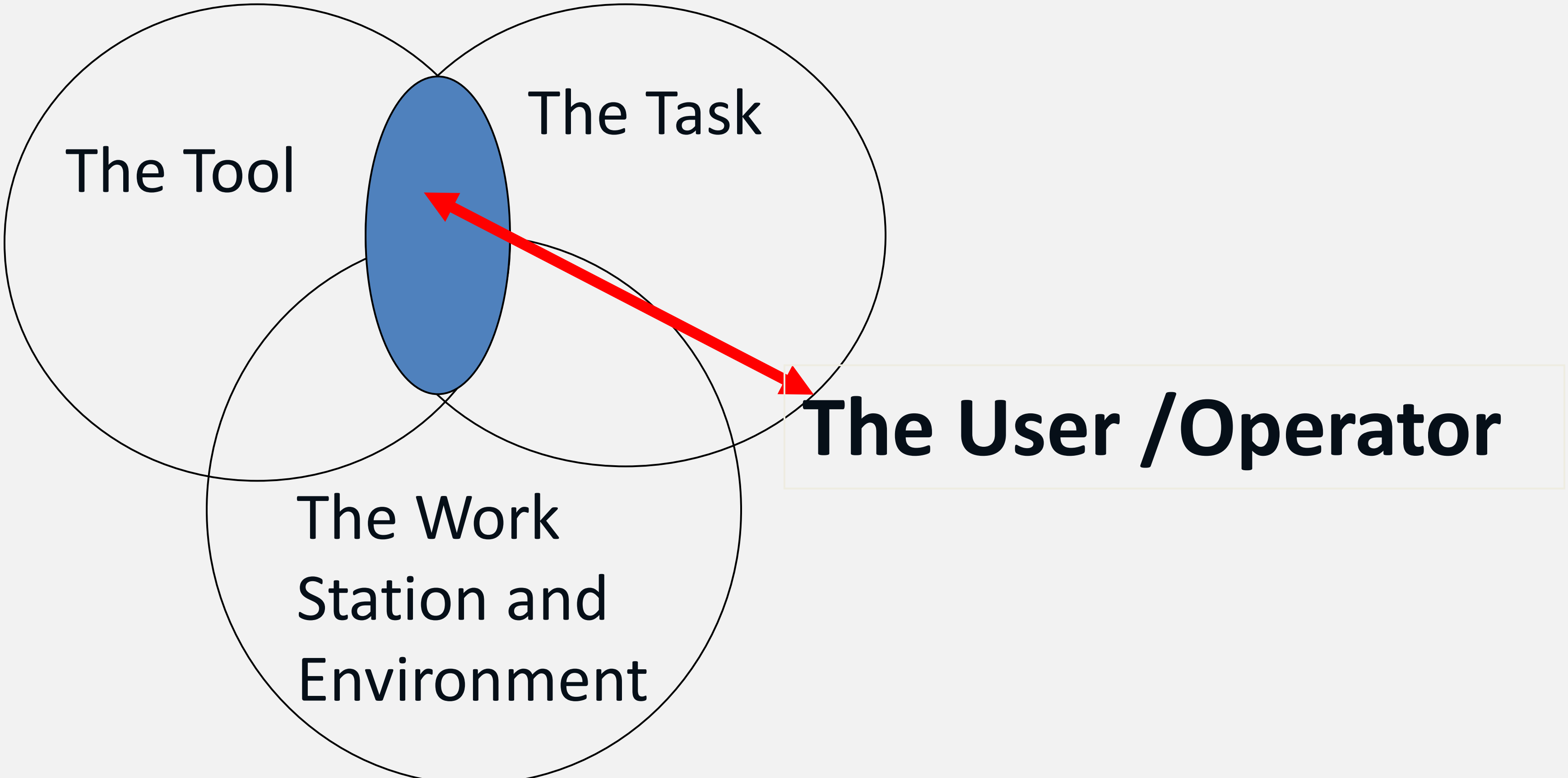

Biomechanical Modeling Methods
Anthropometric Methods
Mechanical Work Capacity Evaluation Methods
Bioinstrumentation Methods
Kinesiology Methods
Classifying and Evaluating Work
OCCUPATIONAL ERGONOMICS & BIOMECHANICS
Worker Selection Criteria & Training
Hand Tool Design Guidelines
Workplace & Machine Guidelines
Seating Design Guidelines
Material Handling Limits
Improved Performance & Reduced Risk of Mechanical Trauma

Six Pillars of Ergonomic Design

1. ***User Orientation:*** Design and application of tools, procedures, and systems must be user-oriented, rather than just “task” oriented
2. ***Diversity:*** Recognition of diversity in human capabilities and limitations, rather than “stereotyping” workers/users
3. ***Effect on Humans:*** Tools, procedures, and systems are not “inert”, but do influence human behaviour and well-being

4. ***Objective Data:*** Empirical information and evaluation is key in design process, rather than just use of "common sense"
5. ***Scientific Method:*** test and retest hypothesis with real data, rather than "anecdotal" evidence or "good estimates"
6. ***Systems:*** object, procedures, environments, and people are interconnected, affect one another, and do not exist in "isolation"

ERGONOMIC FOCUS



When focusing on the tool, the task, and the environment you are trying to find the best combination for the worker(the user/operator). If the right combination is not achieved then ergonomic problems may arise when the workstation, equipment, tools, or environment do not fit the workers well. This stress can cause immediate or long-term damage to muscles, nerves, tendons, and joints. Most of these ergonomic problems/injuries are caused specifically by forceful or repetitive motion activities or because workers must assume awkward positions because the workplace does not fit the employee.

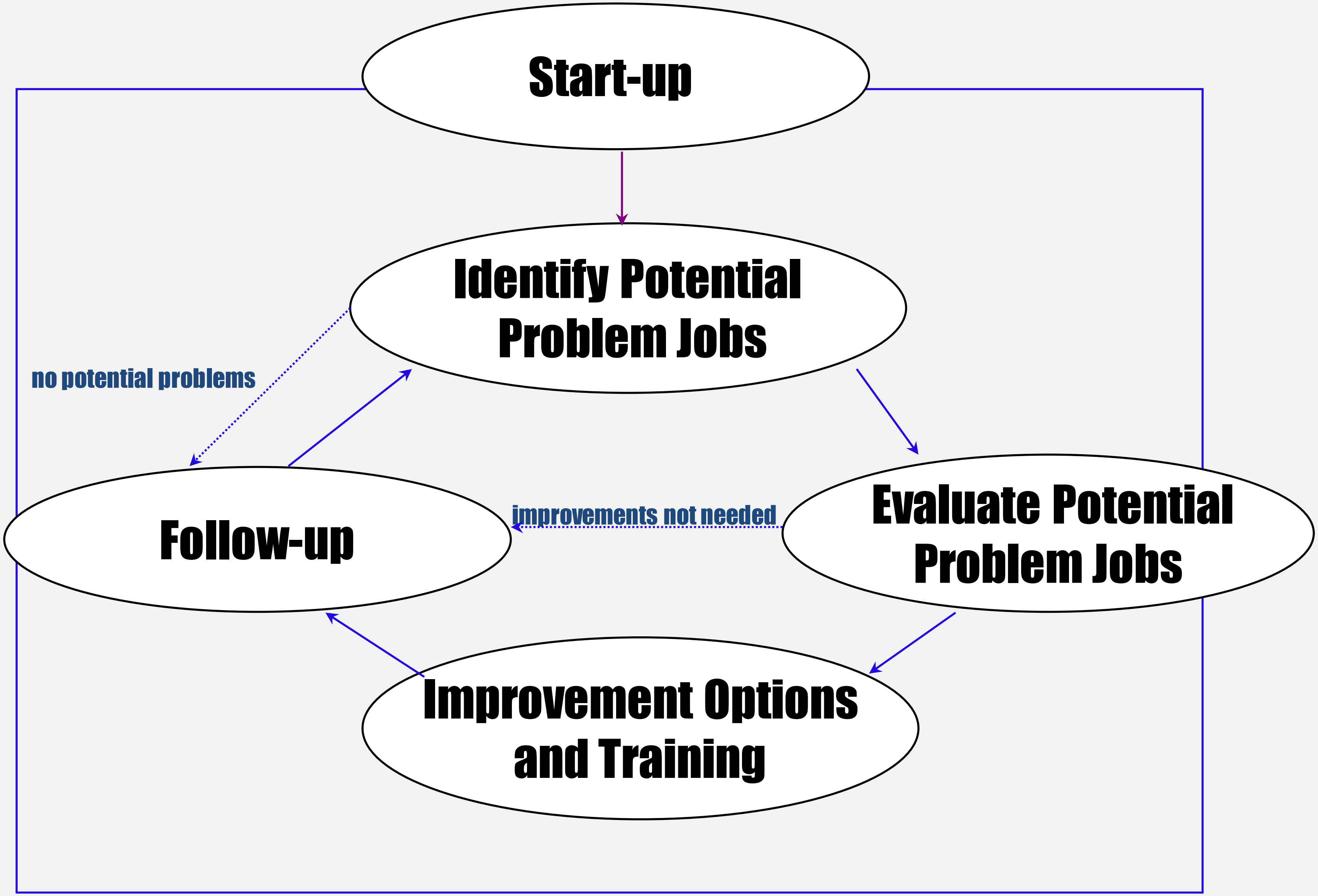
Worker is anyone who performs the task: office workers, custodial, operator. Each brings his/her height, weight, reach, strength and ability

Tool- layout, tool shape, biomechanics.

Task- repetitive, physically demanding, “specialized”, new for the employees, software design, new technology, change, training, job satisfaction, support systems, rest breaks, management system, shift work, production quotas, size, speed.

Environment for the employee and the machine- machine design, furniture, work surfaces, heat, cold, noise, humidity, low light, bright light = complex environment that includes the work station, ambient conditions, and can include the relationship between management and employees.

THE ERGONOMIC PROCESS



Ergonomics – Physical Design

- Who are the users?
- How does technology fit different user dimensions?
- How does technology fit user anatomy?
- How does technology fit user strength?
- How does technology fit different user abilities?
- How safe is the technology (health, comfort, performance)?
- How do users interact with technology?

Ergonomics – Cognitive design

- How do users expect the technology to work?
- How is information displayed?
- How well are stereotypical expectations met?
- How complex is the interface?
- How much training is required?
- What user knowledge assumptions are met?
- How does information facilitate learning and memory?

Ergonomics - Layout

- Are the work items optimally positioned in terms of comfort, convenience, and frequency of use?
- How well does the layout support the work flow?
- Who can be accommodated by the layout?
- How flexible is the layout when work content changes?

Ergonomics - Ambient conditions

- Physical environment conditions at work
- What are the prevailing climate conditions that could effect the work (thermal, luminous, acoustic, vibration, air quality, electromagnetic field)
- What are the exposures?
- What protection is required?

Ergonomics – Work content

- Job design selection and training
- What are the work patterns (shifts etc.)
- What are the work tasks?
- What are the required skills (Physical, Cognitive, Social)?
- What are the training needs?

Two approaches to ergonomics are **reactive ergonomics** and **proactive ergonomics**.

Reactive ergonomics is acting in response to an issue that has already became a problem while, **proactive ergonomics** is to discover potential problems before they take place.

Proactive Ergonomics

- To Emphasize Ergonomics at the Design Stage of Work Processes
- To Design Operations That Ensure Proper Selection and Use of Tools, Job Methods, Workstation Layouts, and Materials
- Build a More Prevention-Oriented Approach Using Knowledge Gained From the Ongoing Ergonomics Process

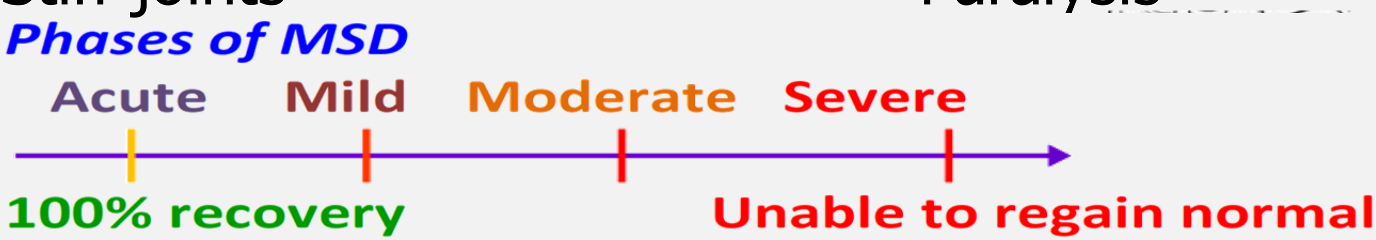
Proactive Ergonomics

- Design Strategies Should Emphasize Fitting Job Demands to the Capabilities and Limitations of Workers
- Design Strategies Should Target Causes of MSDs - Engineering Approaches are Preferred Over Administrative Approaches

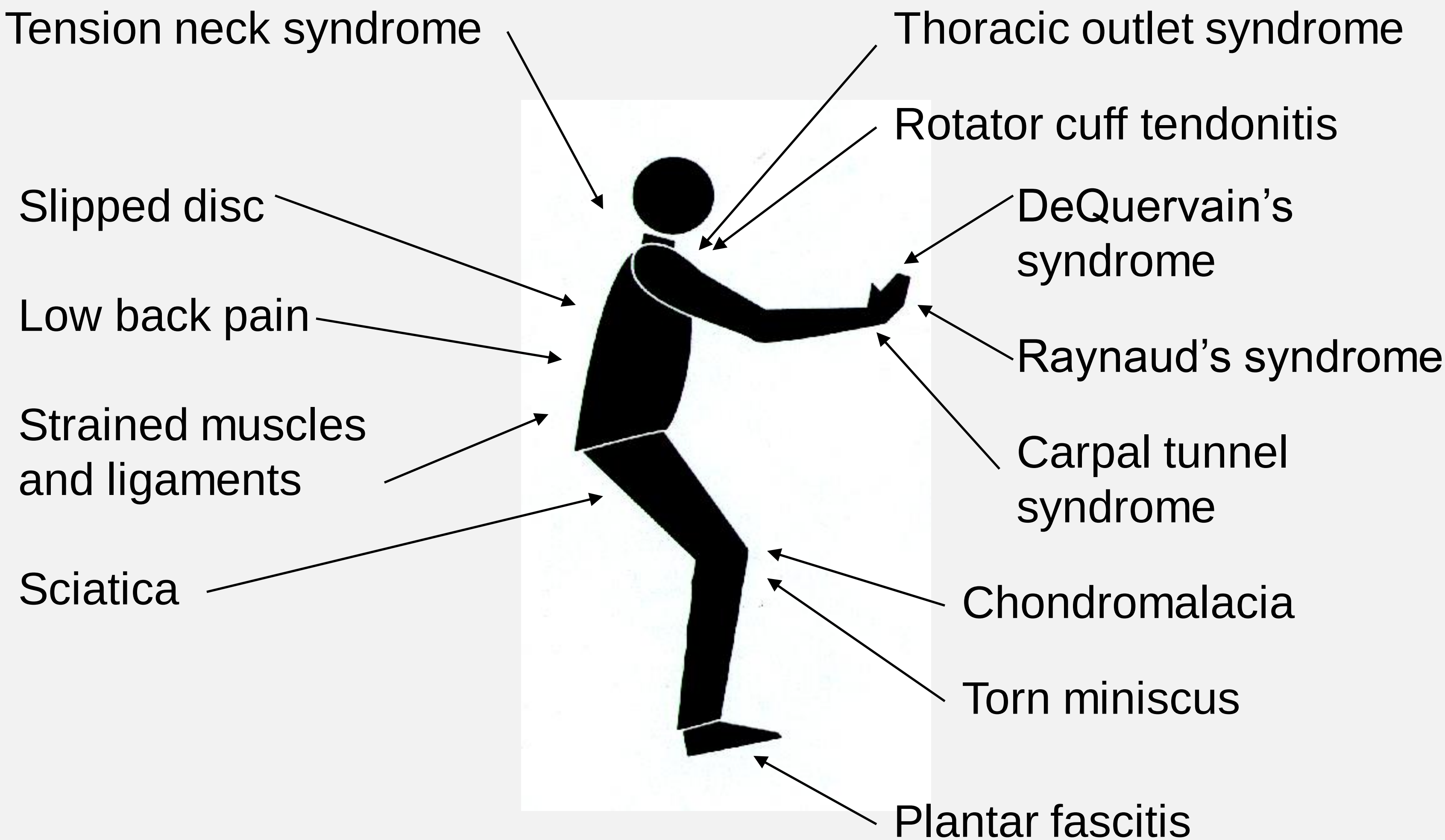
Common Work-Related MSDs

Musculoskeletal Disorders (MSDs)

- Affect the muscles, nerves, blood vessels, ligaments, and tendons
- Symptoms
  - Discomfort
  - Pain
  - Numbness
  - Loss of motion/flexibility
  - Spasticity
  - Stiff joints
  - Burning
  - Swelling
  - Tingling
  - Inflammation
  - Throbbing
  - Paralysis



Source: *Prevention of Musculoskeletal Disorders in the Workplace* (n.d.), OSHA Safety and Health Topics, https://www.osha.gov/SLTC/ergonomics/


Tension neck syndrome
Thoracic outlet syndrome
Rotator cuff tendonitis
Slipped disc
DeQuervain's syndrome
Low back pain
Raynaud's syndrome
Strained muscles and ligaments
Carpal tunnel syndrome
Sciatica
Chondromalacia
Torn miniscus
Plantar fascitis

Common Work-Related MSDs

- Common MSD disorders:
  - Carpal Tunnel Syndrome
  - Tennis Elbow
  - Bursitis
  - Ischemia
  - De Quervain's
  - Sciatica
  - Herniated Discs
  - Neck strain/disability
  - Tendinitis
  - Rotator Cuff
  - Neuritis
  - Reynaud's Syndrome
  - Trigger Finger
  - Thoracic Outlet Syndrome
  - Epicondylitis
  - Back strain/disability

MSDs

Joints (connect bone to bone)--repetitive forceful movements can result in softened cartilage which can lead to growths, degenerative disc disease, osteoarthritis

Muscles (provide the force to perform a task—squeeze and relax)-if contraction is prolonged, blood flow is reduced and waste is not removed fast enough or if not enough rest---muscle irritation, injury and pain

Tendons (fiber muscles attaching muscles to bones)—(hand, wrist, forearm, elbow, shoulder i.e. tendonitis, ganglion cyst, bursitis)

Nerves (surrounded by muscles, tendons, ligaments and blood vessels and carry signals from brain to control muscle activity, temperature, pain,)---tissues surrounding nerves swell and squeeze or compress nerves; e.g. thoracic outlet syndrome and carpal tunnel

Risk Factors Associated with MSDs

Risk factors of MSD injuries:

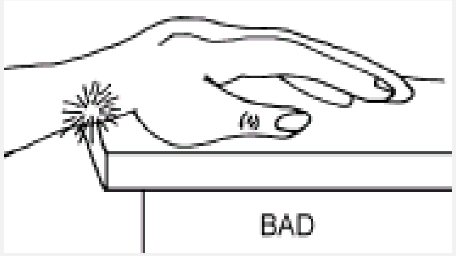
- Dependent upon:
  - Work positions and postures
  - How often task is performed
  - Level of required effort and duration of task

Using ergonomics during work activities makes the work easier on your body and often helps you find ways to do your work more efficiently.

Source: *Prevention of Musculoskeletal Disorders in the Workplace* (n.d.), OSHA Safety and Health Topics, https://www.osha.gov/SLTC/ergonomics/identifyprobs.html

Risk factors and causes of MSD's

- Repetition (task or series of motions performed over and over)
- Heavy, Frequent, or Awkward Lifting
- Force (amount of physical effort required to complete task)
- Awkward Posture (reaching, twisting, bending, holding fixed positions)
- Hand Intensive Work
- Static Posture
- Contact Stress (localized pressure exerted against the skin by external force)
- Temperature Extremes
- Vibration   Bad body mechanics
- Psycho Social   WORK STRESS !!



Repetition

- If you find yourself doing a job task over and over, you should take adequate breaks from the repetitive motion. This means:
  - Get up and move around (move your printer to a location where you have to get up.)
  - During a break - roll your wrist and hands, this will help if you've been typing for a long time.
  - Try to vary your tasks as much as possible so you aren't in a position where you have to keep doing repetitive motions.

Forceful Exertion

- To minimize forceful exertion - do not type with much force, use as light a touch as possible.
- With everything we pick up, or push against, we should try and do it with as little force as possible.
  - This means no pounding the keyboard!!

Awkward Posture

- The location of the telephone may cause you to have an awkward posture that you may not be aware of…..
  - Make sure your telephone is within easy reach.
  - Make sure you do not have to twist (awkward posture) at the waist to reach the phone.

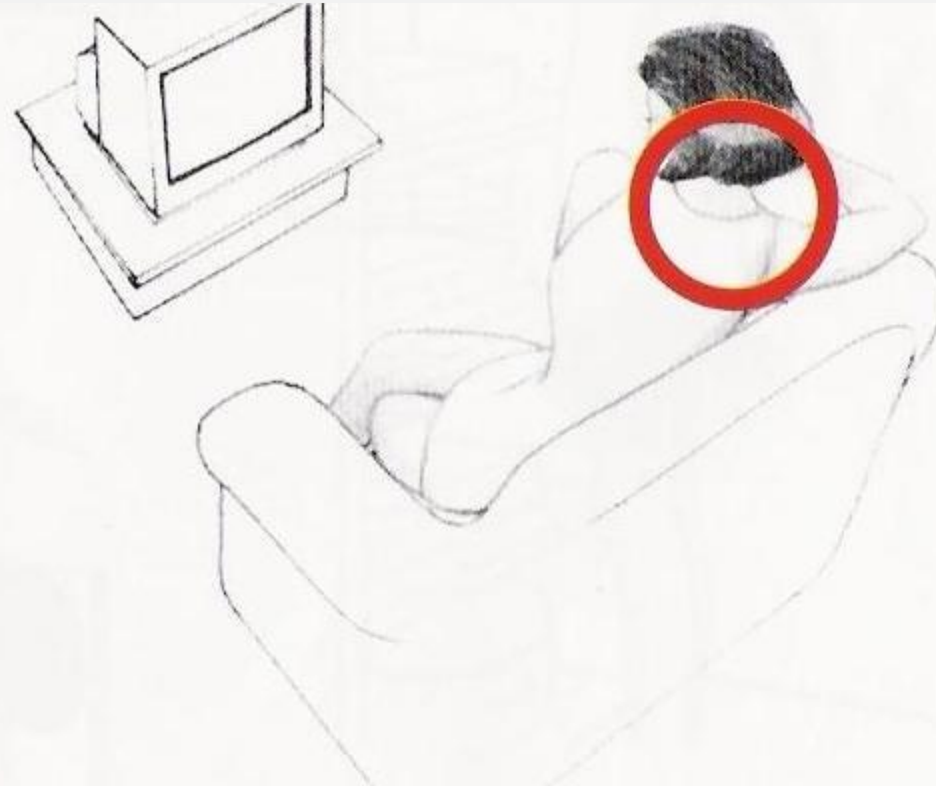
Contact Stress

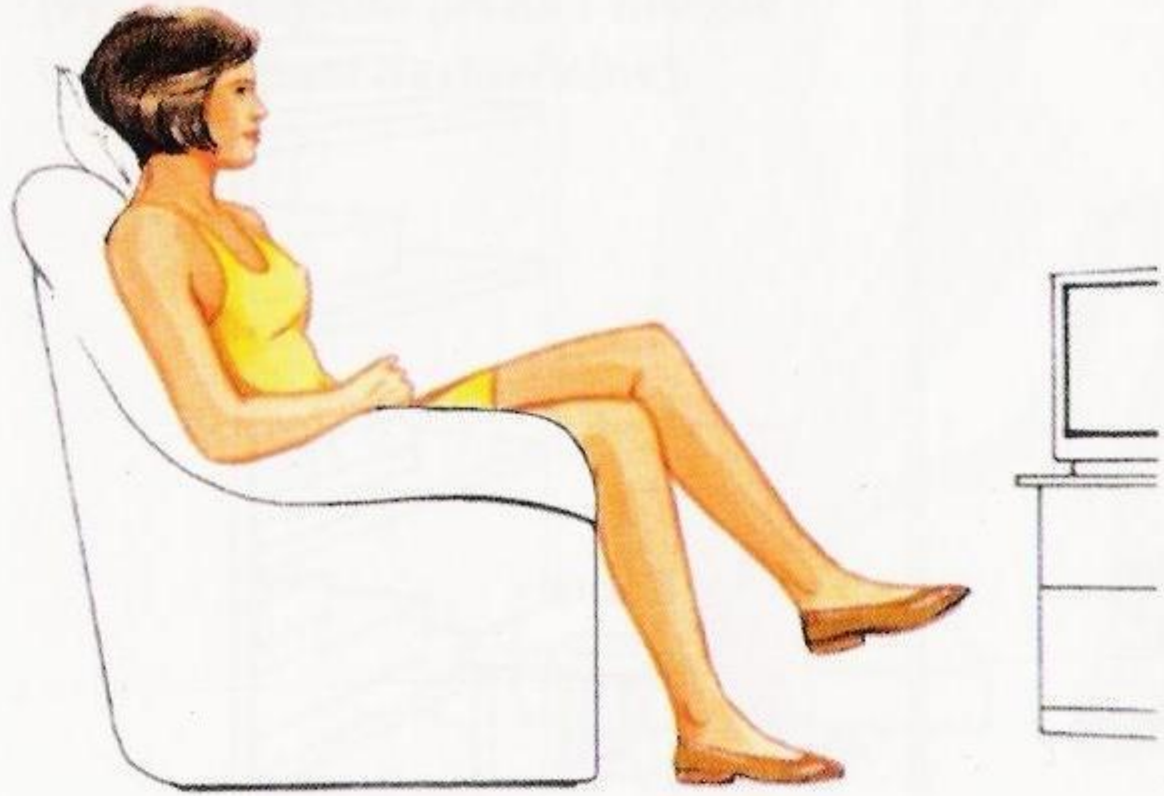
- There are a couple of places you may feel contact stress:
  - If you are resting your wrist on a sharp edge you are creating a contact stress.
    - To fix - do not rest your wrists on anything that will leave an indent mark on your skin.
  - If the chair you are sitting in has a seat pan that pushes against the back of your knees you are experiencing a contact stress.
    - You may need to get a chair with a sliding seat pan to give you enough room between the edge of the seat and the back of your knees.

Home ergonomics

5.

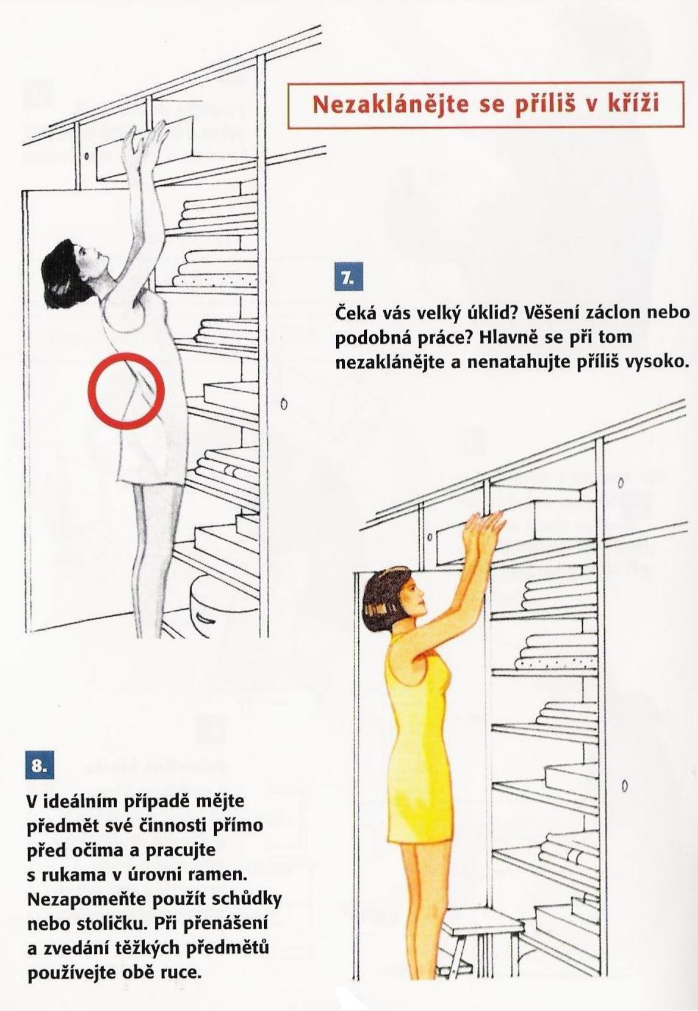
Neseďte zkrouceni při sledování televize!





6.

Pohodlné křeslo s opěrkou hlavy je lepší než měkká pohovka. Polštářek pod hlavu bude pro vaši krční páteř přímo požehnáním.



Nezaklánějte se příliš v kříži

7.

Čeká vás velký úklid? Věšení záclon nebo podobná práce? Hlavně se při tom nezaklánějte a nenatahujte příliš vysoko.

8.

V ideálním případě mějte předmět své činnosti přímo před očima a pracujte s rukama v úrovni ramen. Nezapomeňte použít schůdky nebo stoličku. Při přenášení a zvedání těžkých předmětů používejte obě ruce.

Nepředklánějte se příliš v kříži

9.

Máte před sebou vysávání, žehlení nebo podobnou práci? Hlavně při tom nehrbte záda!

10.

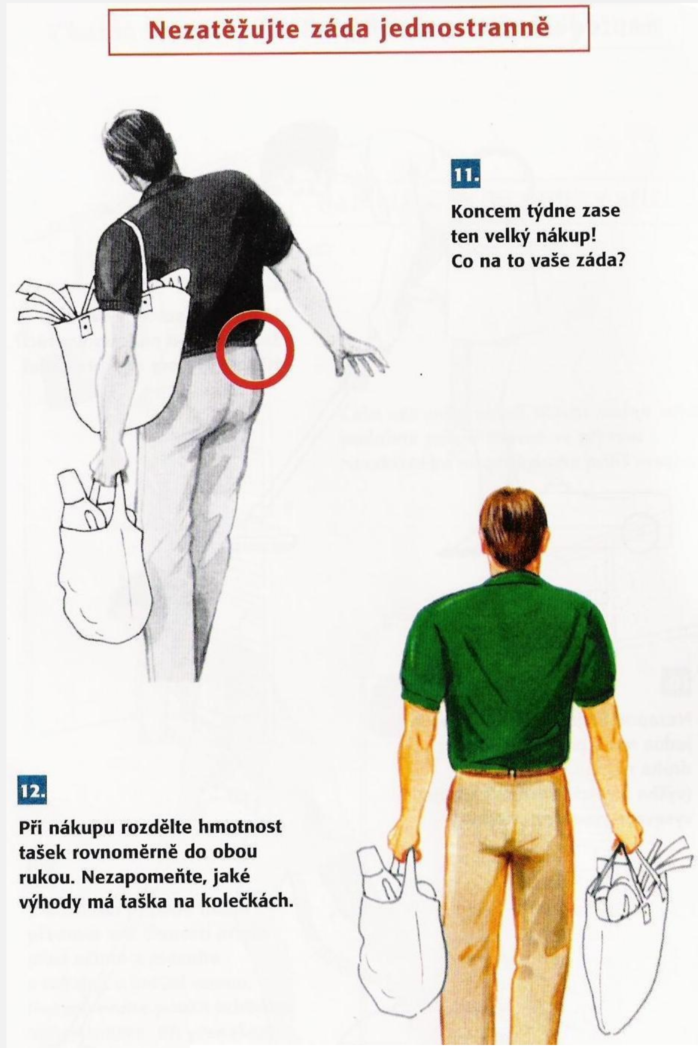
Nezapomínejte na správný postoj: jedna noha pokrčená vpředu, druhá napnutá vzadu (výška žehlicího prkna i rukojeť vysavače jsou nastavitelné).

Cleaning

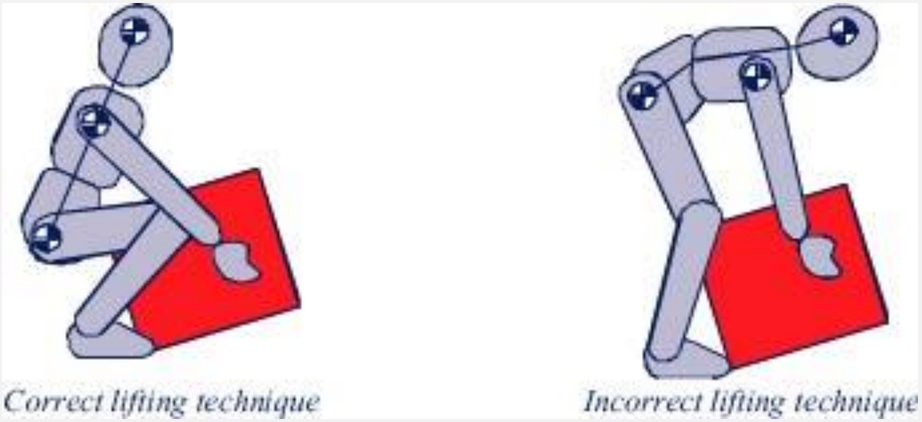
Hauling

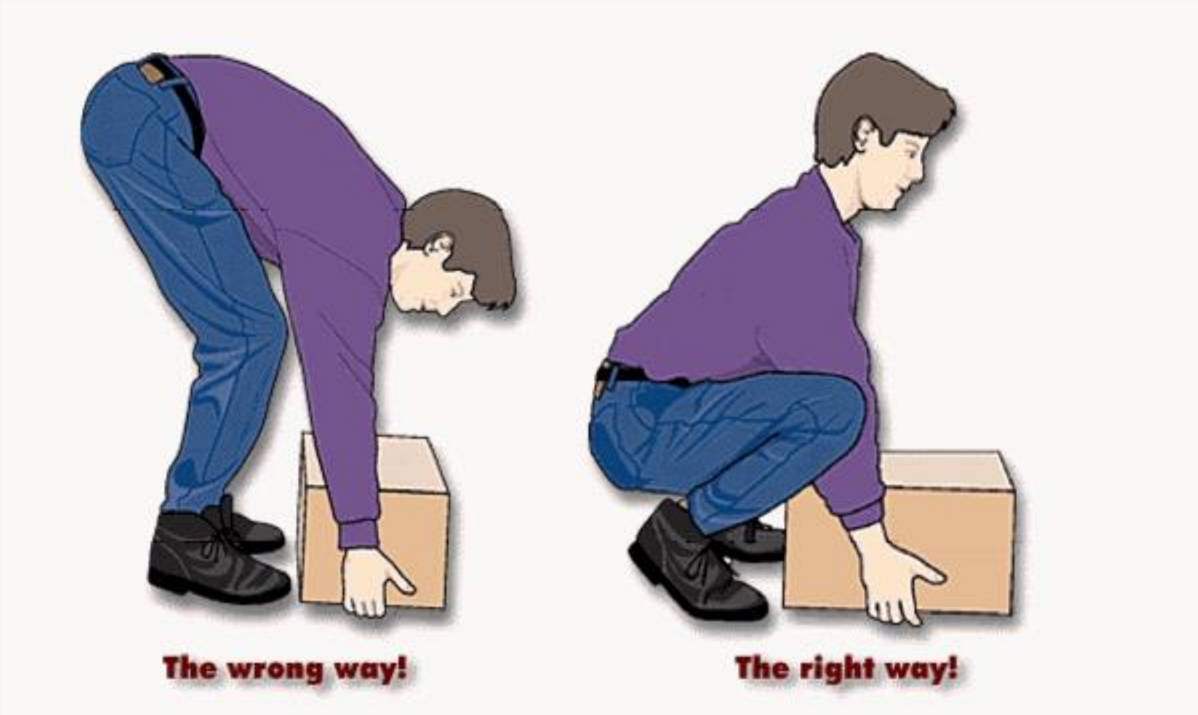
https://www.motucko.cz/modely

Shopping ergonomic

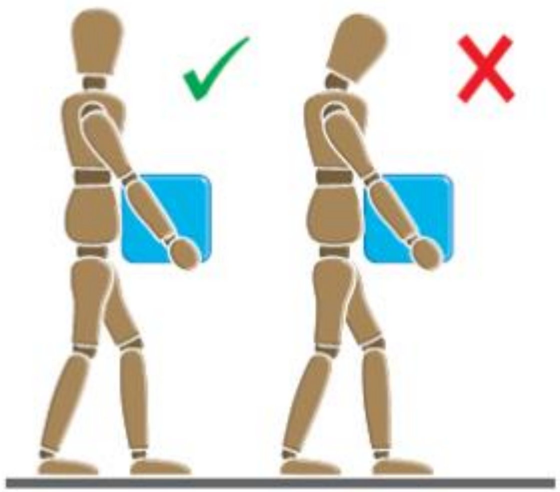


Correct and Incorrect Techniques

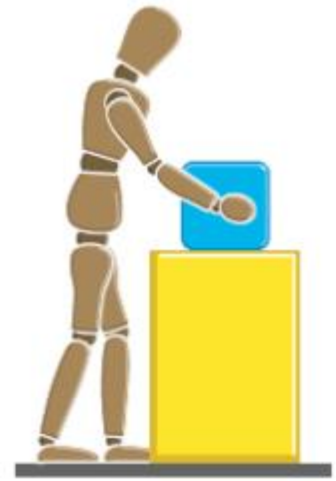




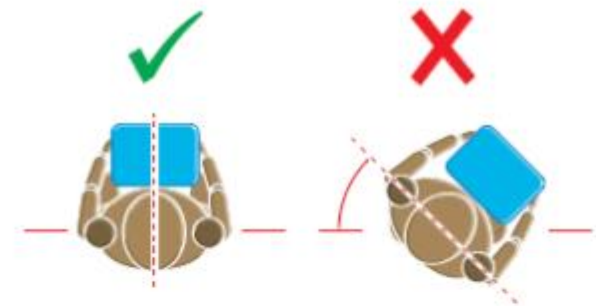
Correct and Incorrect Techniques



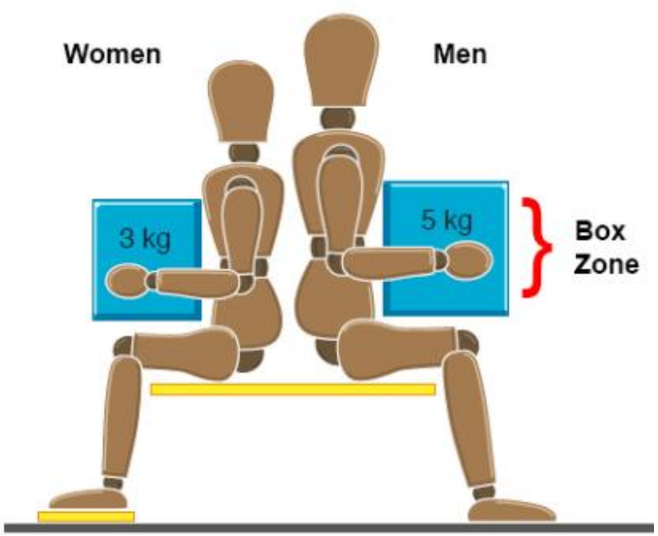
Keep the head up when handling

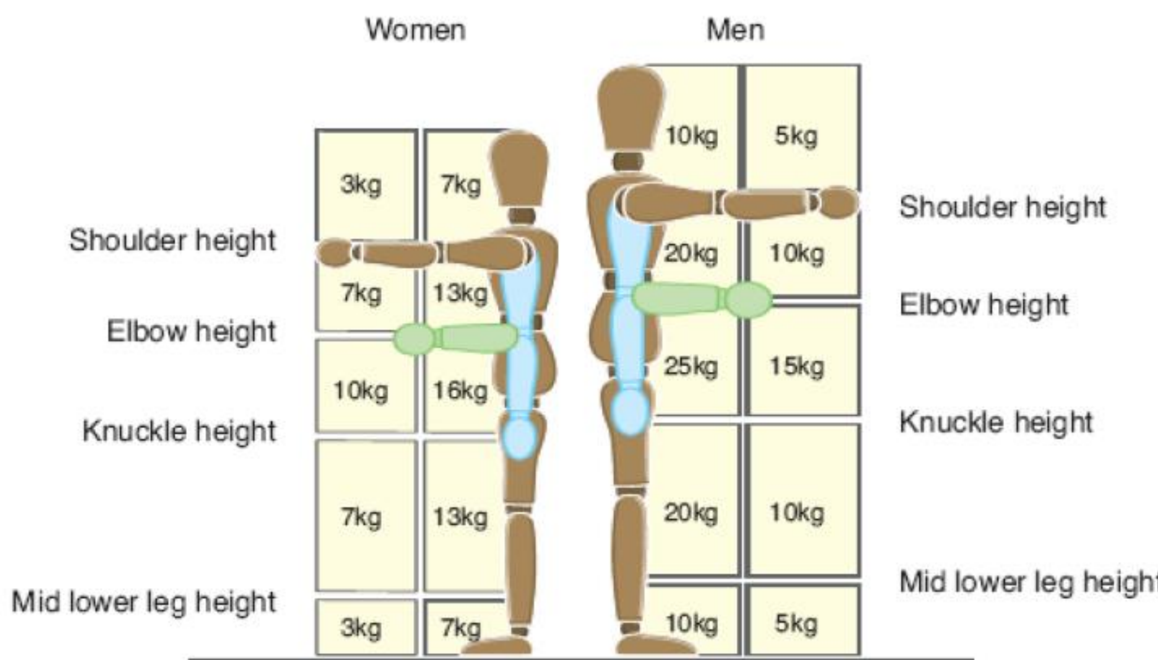


Put down, then adjust



Avoid twisting the back or leaning sideways, especially while the back is bent





Risk Factors Associated with MSDs

- Examples of risk factors include:
  - Exerting excessive force
    - Lifting heavy objects/people
    - Pushing or pulling heavy loads
    - Manual pouring materials
    - Maintaining control of equipment or tools
  - Performing same/similar tasks repetitively

Source: *Prevention of Musculoskeletal Disorders in the Workplace* (n.d.), OSHA Safety and Health Topics, https://www.osha.gov/SLTC/ergonomics/identifyprobs.html

Risk Factors Associated with MSDs

- Working in awkward postures or same postures for long periods
  - Prolonged/repetitive reaching above shoulder height
  - Kneeling
  - Squatting
  - Leaning over a counter/bending
  - Using a knife with wrists bent
  - Twisting the torso while lifting
- Localized pressure into the body part
  - Pressing the body/part of the body against hard or sharp edges
  - Using the hand as a hammer

Risk Factors Associated with MSDs

- Cold temperatures
  (in combination with other risk factors)
- Vibration
  - Whole body
  - Hand-arm
- Combined exposure to
  several risk factors

Source: *Prevention of Musculoskeletal Disorders in the Workplace* (n.d.), OSHA Safety and Health Topics, https://www.osha.gov/SLTC/ergonomics/identifyprobs.html

Ergonomic Control Methods

Methods of protecting against MSDs:

- Establish ergonomics program
  - Training
  - Feedback from all levels
- Conduct job hazard analysis (JHAs)
- Early recognition and reporting of potential MSDs

What causes WMSDs? Work-related Musculo-Skeletal Disorders

- Heavy, Frequent, or Awkward Lifting
- Pushing, Pulling or Carrying Loads
- Working in Awkward Postures
- Hand Intensive Work

There are many things that everyone does on the job and at home that could contribute to a WMSD if they are done for long enough periods of time. These activities are called risk factors. Risk factors include heavy, frequent or awkward lifting, pushing, pulling or carrying, working in awkward postures, and hand intensive work that requires the use of high hand forces and repetitive motions.

Risk Factors

Risk of injury depends upon:

- Duration of exposure (how long)
- Frequency of exposure (how often often often often)
- Intensity of exposure (how MUCH)
- Combinations of risk factors +++

Duration

- Duration – You usually need hours of exposure before risk factors become a concern

- Exposure can be all at one time or cumulative over the day

You need to be exposed to risk factors for quite a while before you can be injured by them. Remember, we're talking about hours of exposure here, not just minutes.
You don't need to be exposed to a risk factor for hours on end to increase your chance of being injured, though. For example, it's easy to see how working bent over for two hours straight could cause back strain. While it's less likely to cause an injury, you can also strain your back by working bent over 15 minutes at a time for a total of two hours per day.
Something to keep in mind, it's not that these injuries occur from a single day of exposure. It's when you have these risk factors as a regular part of your job with multiple days of exposure that injuries can occur.

Frequency

Frequency is often a concern in:

- assembly tasks
- sorting tasks
- loading or off-loading materials
- inventorying products
- product stocking
- software programming
- telemarketing
- customer service

Frequency addresses the speed at which you work. It can be measured in units per unit time (ie.boxes per hour). Some people get paid by the product amounts they assemble, pick, load, unload, stack, etc. With numbers as a motivator, sometimes repetition can be dangerous. When combined with force, and duration, doing a task with high frequency can significantly increase a person's potential for injury. What can be defined as frequent, changes with the nature of the task. Lifting 30 lb boxes more than 5 times a minute can be considered frequent, while typing more than 5 words a minute probably wouldn't. Use your good judgement to determine what is frequent for the various tasks in your workplace.

Intensity

Intensity refers to:

- weight in pounds of items lifted or carried
- grip or pinch force of lifted or manipulated items
- vibration level (meters/second^2)
- force on keys when typing

Combinations of risk factors

- Exposure to more than one risk factor at a time greatly increases the risk of injury.
- For example:
  - Bending and twisting while lifting
  - Repetitive, forceful use of the hands with the wrists bent

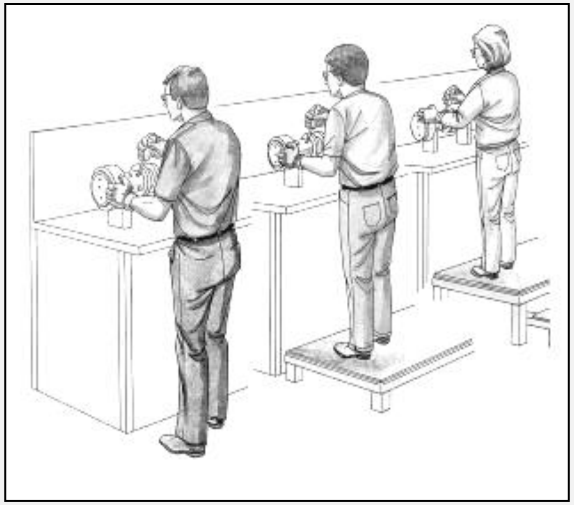
Ergonomic Control Methods

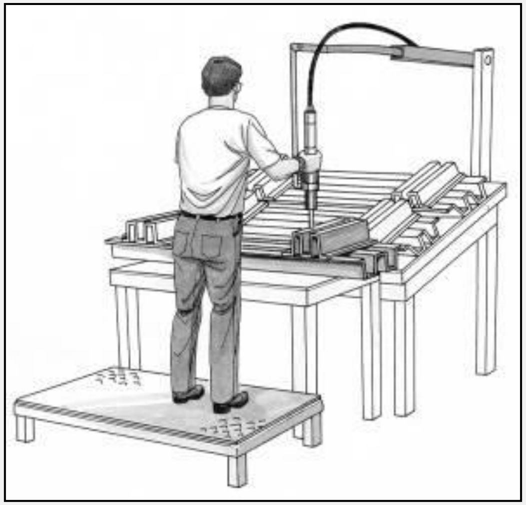
Job Hazard Analysis		
Tasks	Hazards	Controls

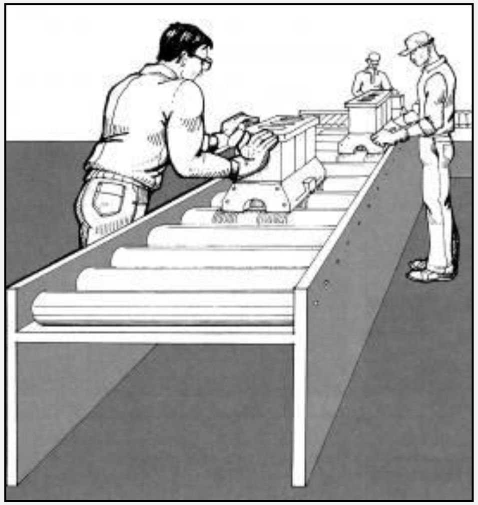
This table provides an example of a tool that can be used when conducting a job hazard analysis. The first column provides a list of tasks performed by a job; the middle column is provided for listing identified hazards; and, the third column provides a list of controls that can be used to mitigate the hazards.

Ergonomic Control Methods

- Examples of **engineering controls**
  - Work station design and setup
  - Ergonomically designed tools
  - Ergonomically designed equipment
  - Load weight reduction







Engineering Controls (implement physical change to the workplace, which eliminates/reduces the hazard on the job/task)

- Use a device to lift and reposition heavy objects to limit force exertion
- Reduce the weight of a load to limit force exertion
- Reposition a work table to eliminate a long/excessive reach and enable working in neutral postures
- Use diverging conveyors off a main line so that tasks are less repetitive
- Install diverters on conveyors to direct materials toward the worker to eliminate excessive leaning or reaching
- Redesign tools to enable neutral postures

Ergonomic Control Methods

- Examples of **proper work practices:**
  - Proper lifting techniques (NIOSH)
  - Team lift heavy/bulky/awkward loads
  - Stretch
  - Work rotation
  - Task variety
  - Increase rest breaks

Ergonomics at Work

Risk of injury - Heavy lifting

Cart reduces risk

These pictures show the difference between lifting and moving something heavy and awkward by hand (in this case a roll of carpet) and moving the same thing with the help of a co-worker and mechanical assistance (in this case a carpet dolly).
Lifting the carpet without assistance might create a risk for back or shoulder injury. The science of ergonomics teaches us that using the dolly puts a lot less strain on the back and shoulders, and it's also less tiring overall. The worker who gets help is a lot more likely to have a little energy left at the end of the day, and in the long run is a lot less likely to have injuries and miss work.
Ergonomics can be as simple as using a dolly to move something instead of lifting by hand. Ergonomics is about making jobs easier and reducing the risk of injury.

Ergonomic Control Methods

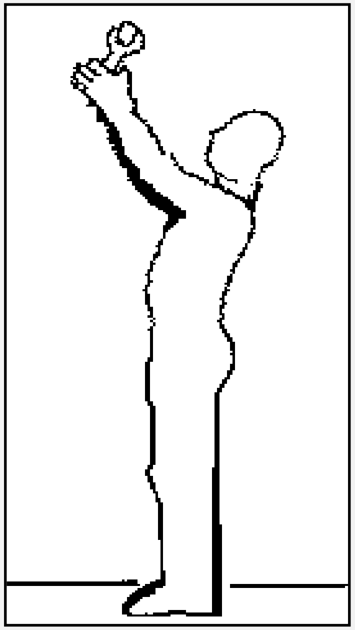
Changes made to workers to reduce exposure to risk factors

- Examples of **PPE:**
  - Gripping gloves
  - Knee pads
  - Vibration gloves
  - Thermal gloves
  - Lifting straps
  - Shoulder harness
  - Lifting braces

Ergonomic Control Methods

Physical ergonomic **hazards** and **solutions**:

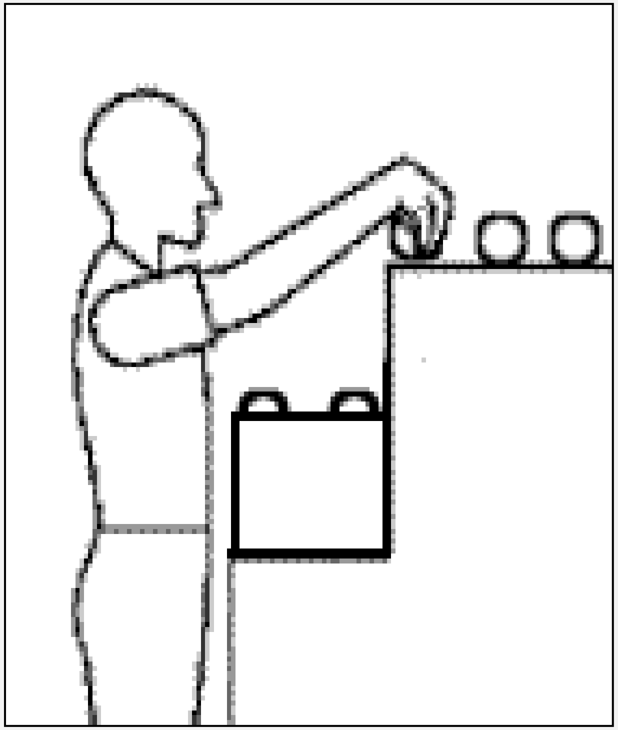
- Reaching above the head/shoulders - **hazards**
  - Working with the hands above head for more than 2 hours per day



Source: *Ergonomics eTool: Solutions for Electrical Contractors* (2003), OSHA eTool, https://www.osha.gov/SLTC/etools/electricalcontractors/index.html

Ergonomic Control Methods

– Working with the elbows above shoulders for more than 2 hours per day



“**Potential Hazards**:
•Awkward postures while pulling with the hands above the shoulder cause an increased load imposed on the shoulders, neck and back. When performed repeatedly, these tasks may result in overexertion of the back and upper extremities.”

Ergonomic Control Methods

- Reaching above the head/shoulders - **solutions**
  - Keep items within close reach
  - Elevate work areas

Source: OSHA

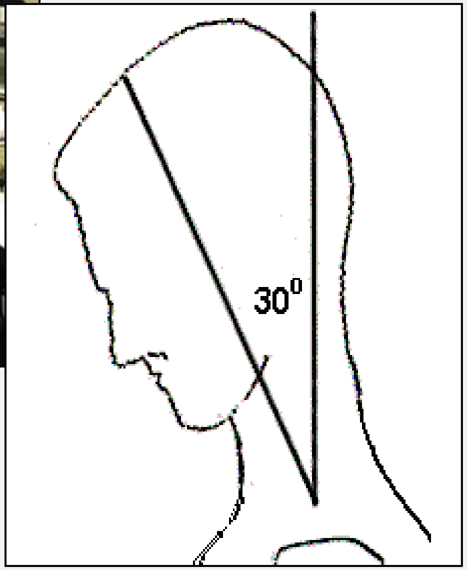
Ergonomic Control Methods

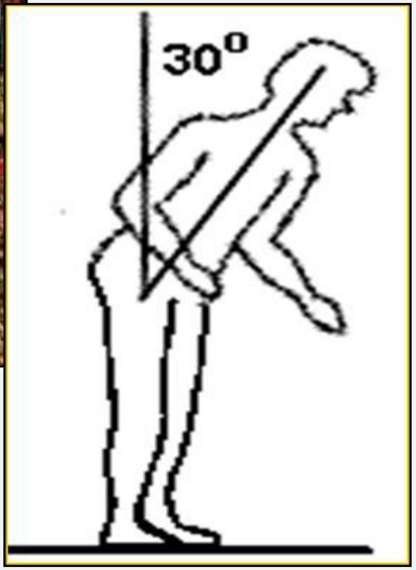
- Reaching above the head/shoulders - **solutions**
  - Remove obstacles
  - Utilize equipment to raise and lower items or move items closer to worker

- Use gravity feed racks (these are racks on shelves with little wheels that allow boxes stored on them to slide forward as the front box is removed. (Kind of like taking a can of beverage out of the cooler case at a convenience store.)
- Small portable forklift

Ergonomic Control Methods

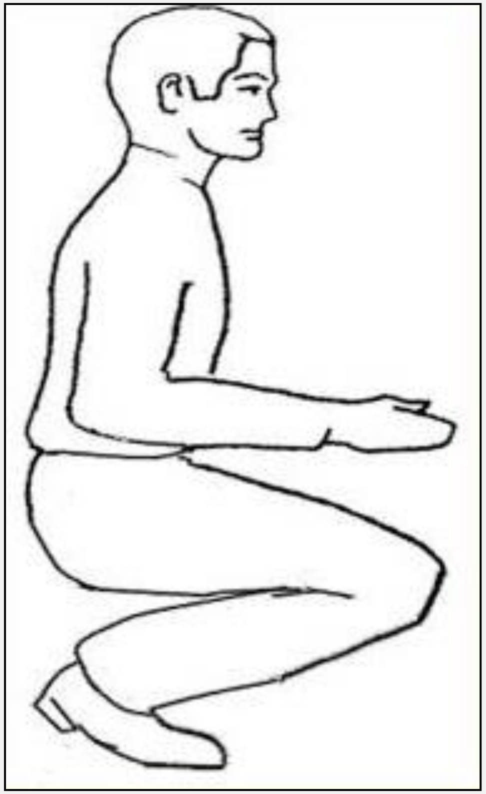
- Awkward body postures - **hazards**
  - Working with the neck or back bent forward more than 30° for more than 2 hours per day





Ergonomic Control Methods

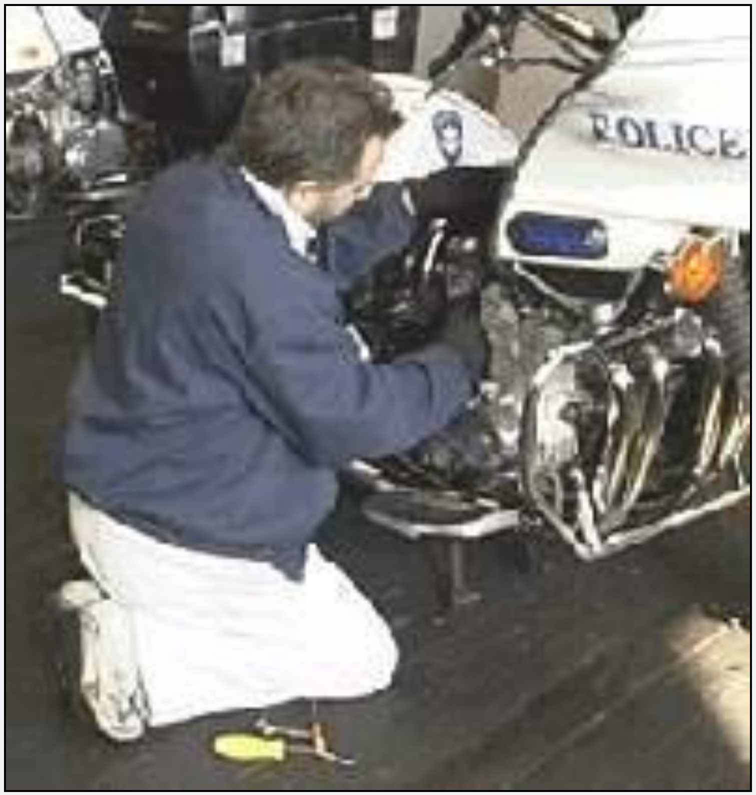
– Squatting for more than 2 hours per day

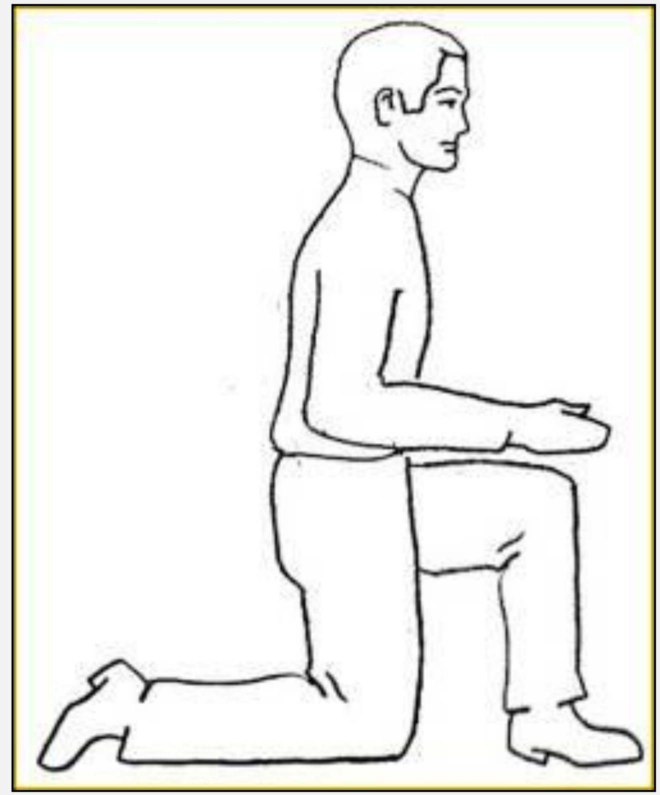


•Squatting is one alternative to bending at the back to get down low, and it's fine to do for short periods of time. Unfortunately it creates a lot of pressure behind the knee cap and can cause knee injuries over time.

Ergonomic Control Methods

– Kneeling for more than 2 hours per day





Ergonomic Control Methods

- Awkward body postures - **solutions**
  - Raise and/or tilt the work for better access
  - Use a stool for ground-level work



Ergonomic Control Methods

- Awkward body postures - **solutions**
  - Use tools with longer handles
  - Alternate between bending, kneeling, sitting, and squatting

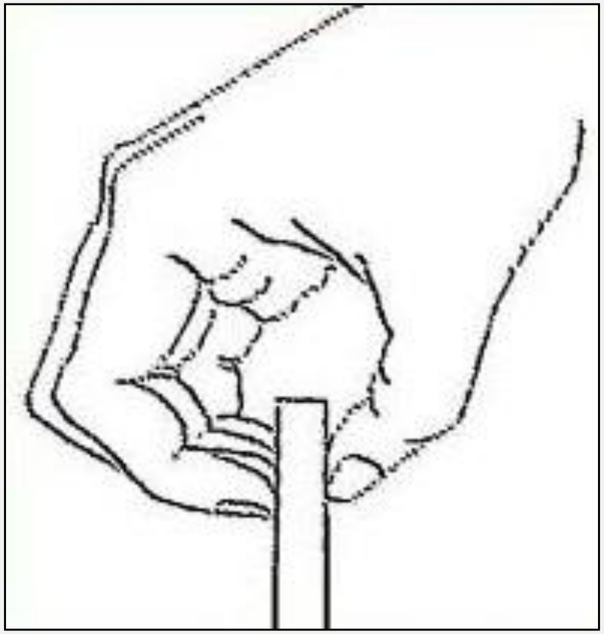


Ergonomic Control Methods

- Awkward grips - **hazards**
  - Gripping 10 or more pounds or force for 2 or more hours per day

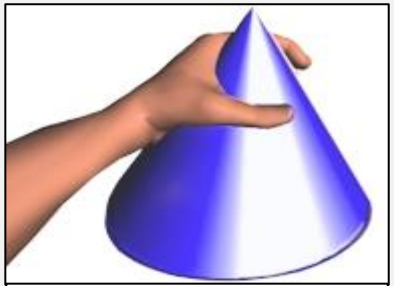
Ergonomic Control Methods

- Awkward grips - **hazards**
  - Pinching 2 or more pounds of weight or 4 or more pounds of force for 2 or more hours per day



Ergonomic Control Methods

- Awkward grips - **solutions**
  - Design work layout to reduce hand-carrying
  - Reduce amount of items carried at one time
  - Use non-pinch grip postures
  - Use ergonomically designed tools/aids
  - Use job/task rotation



"C" shaped posture

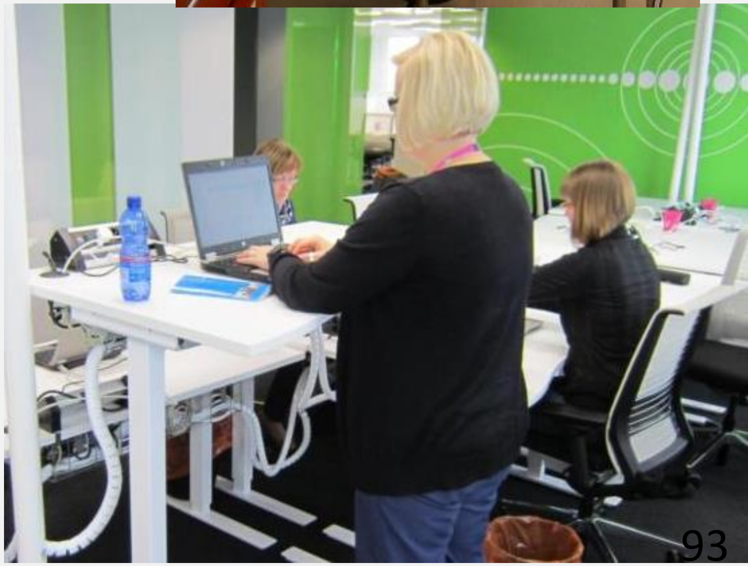
Ergonomic Control Methods

- Repetitive motions - **hazards**
  - Repeating same motion for more than two hours per day with hands, wrists, elbows, shoulders, or neck

Solutions for Baggage Handling, OSHA eTool
https://www.osha.gov/SLTC/etools/baggagehandling/index.html

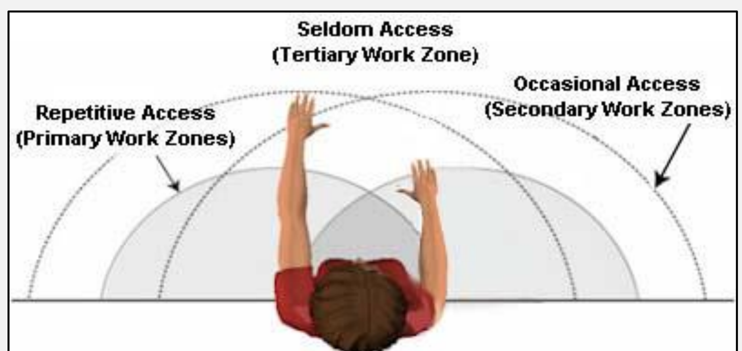
Ergonomic Control Methods

- Repetitive motions - **hazards**
  - Intense keying for more than 4 hours per day

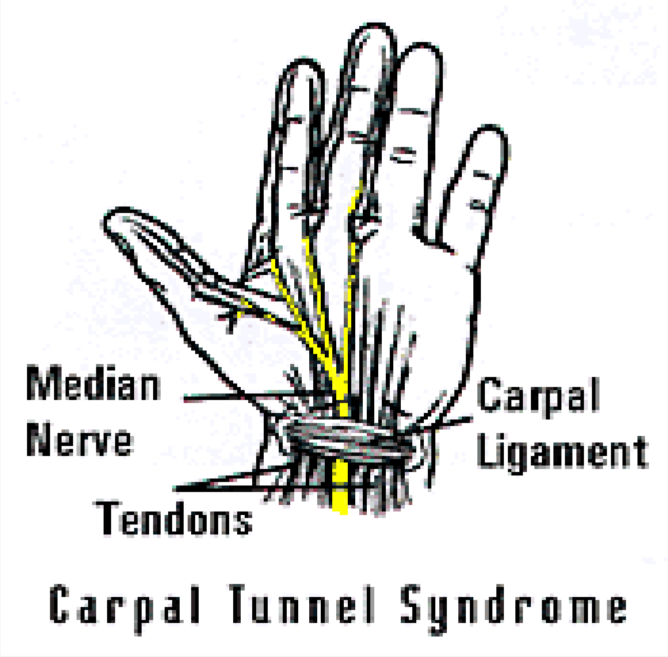


Ergonomic Control Methods

- Repetitive motions - **solutions**
  - Arrange work to avoid unnecessary motions
  - Let power tools and machinery do the work
  - Spread repetitive work out during the day
  - Take stretch pauses
  - Rotate task with co-workers if possible
  - Change hands or motions frequently



Irritation of the median nerve, which runs through a bony channel in the wrist called the carpal tunnel. Usually results from excessive flexing or twisting of the wrist. Have the symptoms/signs of numbness, tingling, pain and weakness in the thumb, index, middle and ring fingers. The pain ... may wake you up at night or worsen when do forceful or repetitive work.



- TRIGGER FINGER SYNDROME- Tendons in the fingers become inflamed, causing pain, swelling, and a loss of dexterity.

- EYE STRAIN - The eyes become strained as a result of poor lighting, glare or viewing from awkward positions. can have visual discomfort, headaches, blurred vision, burning and/or dry eyes, slow refocusing, sensitivity to light, double vision, and after-images. Poor lighting in the work area, glare from windows, lights or other sources, viewing from awkward positions, extended viewing with no breaks. Computer Vision Syndrome is the name of the condition the American Optometric Association defines as the "complex of eye and vision problems related to near work, which are experienced during or related to computer use."

BIOMECHANICS

The science of measuring the amount of force put on the muscles and joints of people when working in different positions.

The activity can be either Static or Dynamic.

Ergonomic Control Methods

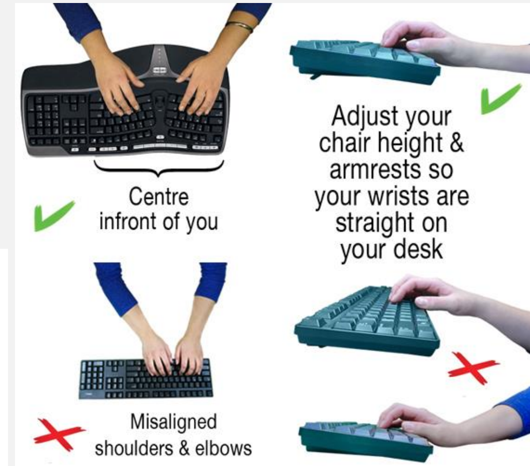
- Localized pressure on body part - **hazards**
  - Pressing the body/part of the body against hard or sharp edges
  - Standing/kneeling for prolonged periods on hard surfaces
  - Using tools with hard handle surfaces or short handles

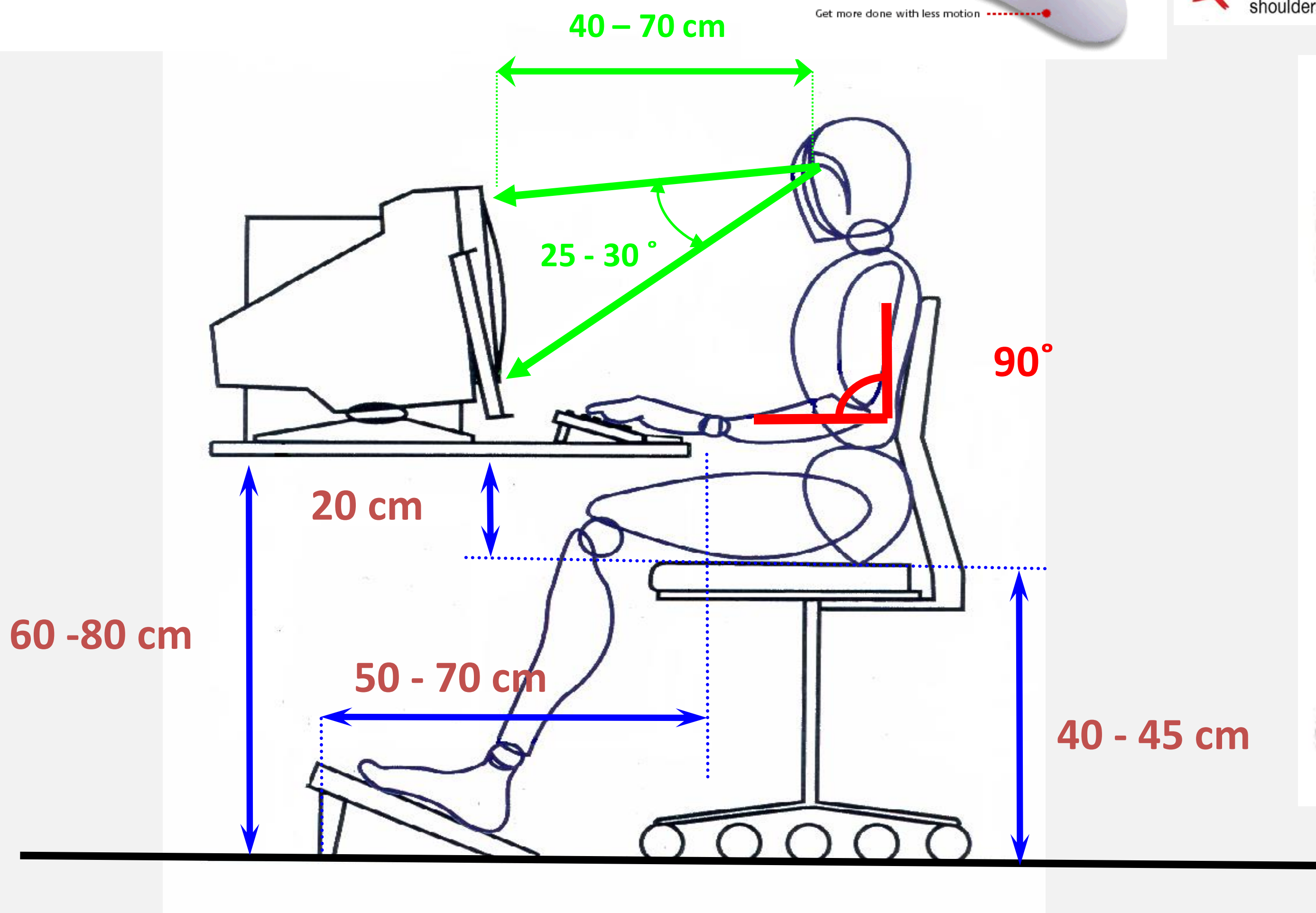
Source: https://www.osha.gov/SLTC/etools/computerworkstations/components_desk.html
"Some desks and computer equipment have hard, angled leading edges that come in contact with a user's arm or wrist. This can create contact stress, affecting nerves and blood vessels, possibly causing tingling and sore fingers."

Source:
https://www.osha.gov/SLTC/etools/electricalcontractors/prefabrication/assembly.html
"Sharp edges on work tables may create contact stress to soft tissues of the forearm, hand, and wrist."

Source: https://www.osha.gov/SLTC/etools/electricalcontractors/installation/using.html
"Short handles may press or rub against the palm and fingers… causing contact stress. Small handle diameter may increase force requirements of tool leading to fatigue, discomfort and pain."

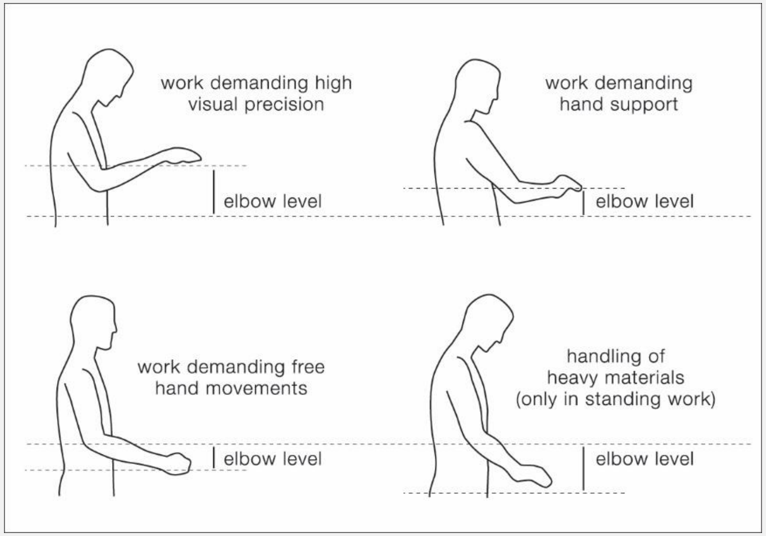

Marble technology provides smooth precision
Comfort and control for left and right hands
Practically maintenance-free
Get more done with less motion

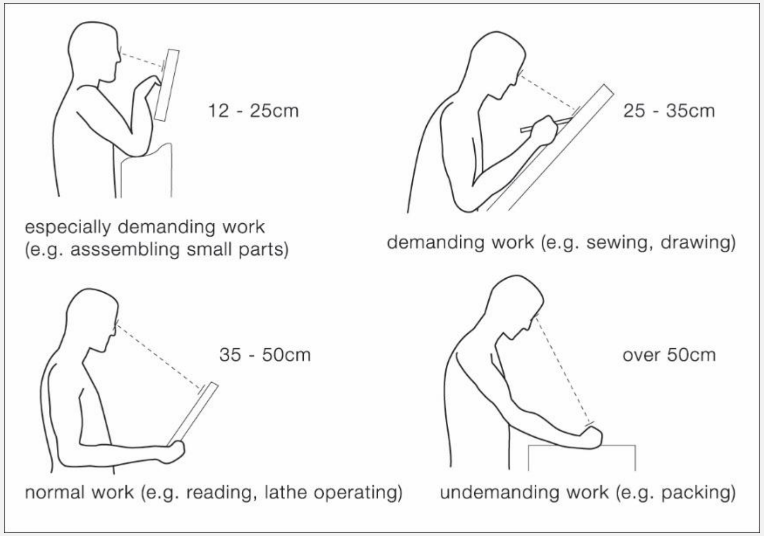

Centre infront of you
Adjust your chair height & armrests so your wrists are straight on your desk
Misaligned shoulders & elbows


40 – 70 cm
25 - 30 °
90°
20 cm
60 -80 cm
50 - 70 cm
40 - 45 cm

Workstation Design – Viewing distances & angles

- Viewing distances proportional to size of work object
  - Small object, shorter viewing distance, higher work surface
- Ensure viewing distances cater for all ages
- Viewing angles vary from 15^{o}-45^{o}



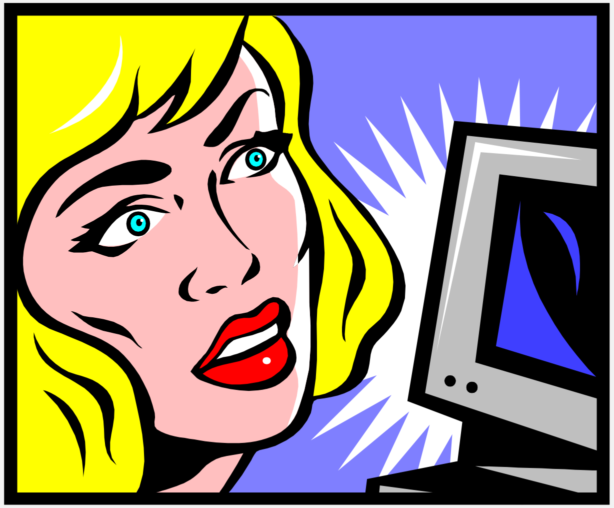


Future planning

Workstation design

- Individual
- Demands
- Repetition
- Environment
- Training

Contrast sensitivity

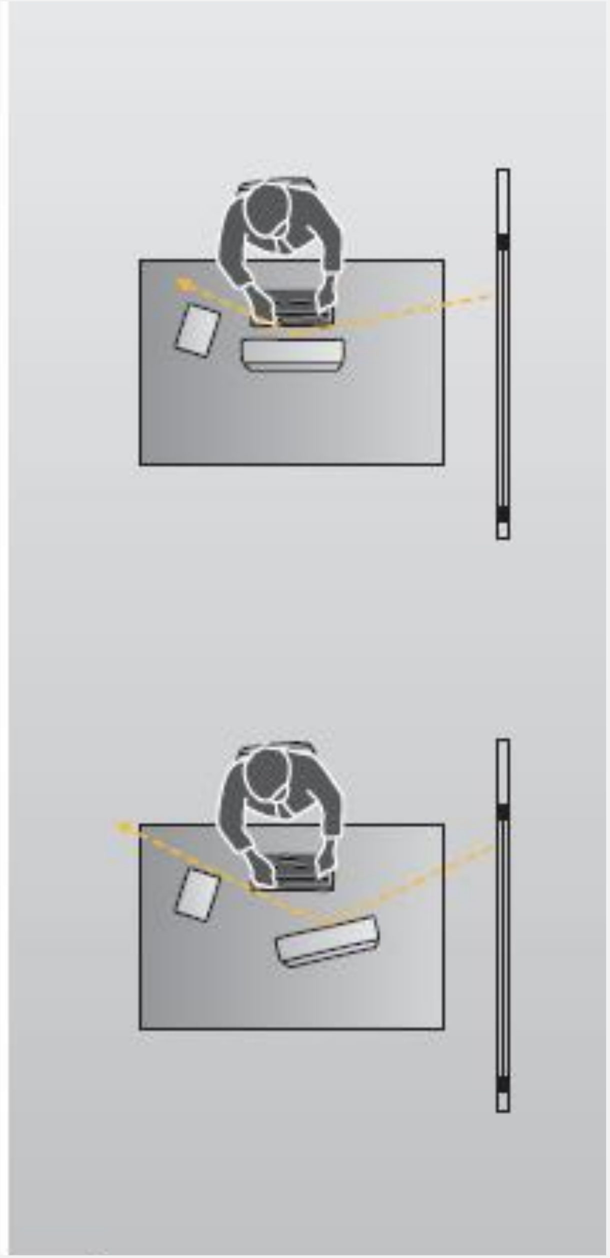


- Low contrast
- High contrast
- Flicker

•Contrast sensitivity refers to the eyes ability to perceive small differences in luminance (light intensity) and so allows for the perception of shape and form, such as to detect an object against a background.

•Contrast sensitivity also includes the eyes' ability to detect light flicker. Light flicker refers to quick, repeated changes in light intensity - light that appears to flutter and be unsteady. Flicker: People can see lights flashing on and off up to about 50 flashes or cycles per second (50 Hertz) – but after this level at higher frequencies most people can no longer distinguish between the individual flickers. At this frequency - the critical 'flicker fusion frequency' or 'flicker fusion threshold' - the flashes appear to fuse into a steady, continuous source of light.

Reflections



Place monitor side on to a window to reduce reflections

Lighting design

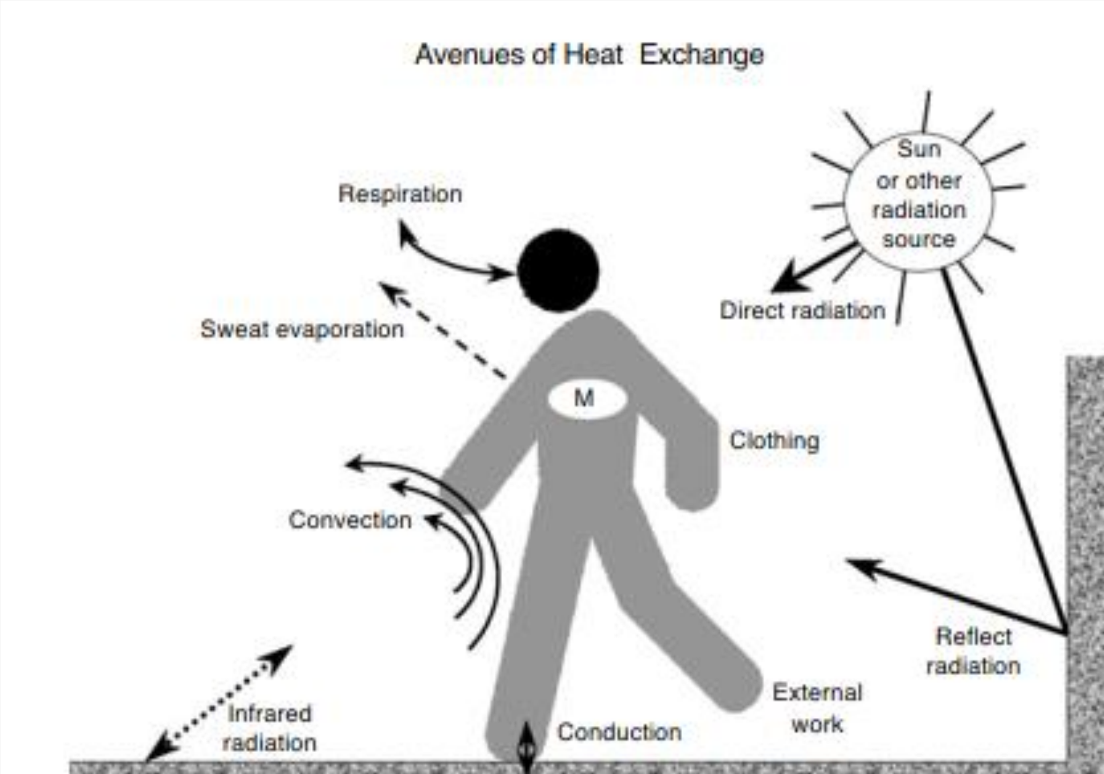
- Task
- Viewer
- Area
- Environment
- Lamp
- Illuminance
- Uniformity
- Maintenance
- Daylight

UOW

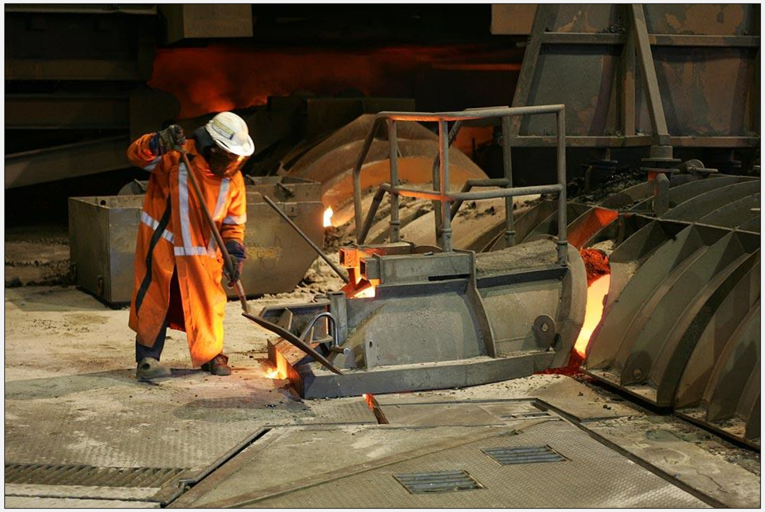
- **Ears and hearing**
- **Noise**
- **Controlling noise exposure**

Nuisance noise

- Loud
- High frequency
- Unaccustomed
- Dislike source
- Unfamiliar
- Intermittent



Exposure to heat



- Engineering
- Work practices
- Personal tolerance

•Enhancing tolerance times through heat acclimatisation; physical fitness; ensuring water and electrolyte losses are replaced.

Exposure to cold

- Engineering
- Work practices
- Personal tolerance

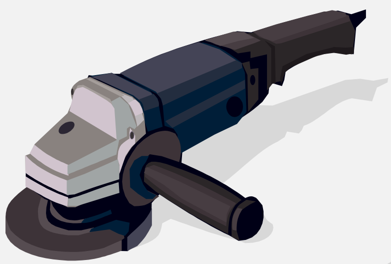
•Monitoring air temperature, air velocity and equivalent chill temperature
•Screening workers who may have a reduced tolerance to cold.

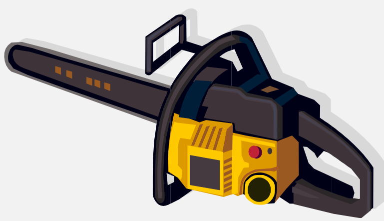
VIBRATION

Source..

- **Handheld power tools**
- **Hand guided powered equipment**
- **Powered machines**

Common tools:
Jackhammer
Rotary hammer
Impact drill
Chainsaw
Angle grinder
Hand-guided machines





The two main types of vibration exposure are:
Hand transmitted vibration, and
Whole-body (WBV).

Whole body vibration

Source:

Sitting in plant

Standing on a work platform

Examples:

Off road machinery in mining, construction, forestry & agriculture

Driving vehicles designed for smooth roads over uneven surfaces / yards

Whole body vibration

High velocity or acceleration of movement

Reduce risk:

- Road maintenance
- Well maintained vehicles
- Cab isolation
- Limiting speed
- Operator training
- Vibration monitoring
- Regular rest breaks

Hearing protection

- Long hair
- Safety glasses
- Earrings
- Fitting earplugs

Correct

Incorrect

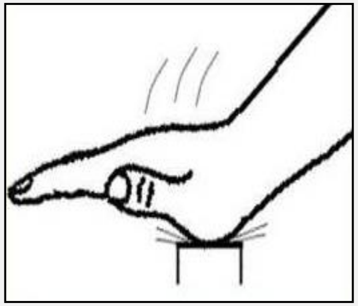
Footwear

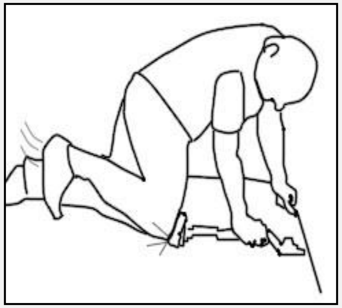
Considerations?

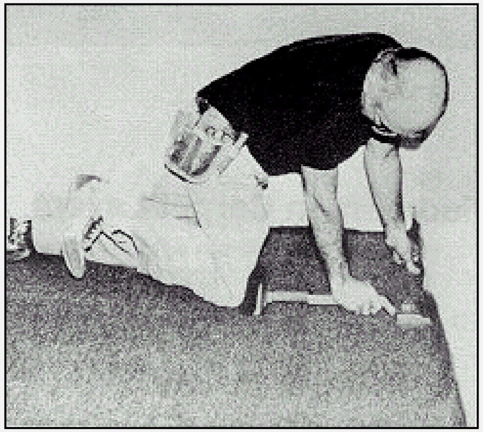
- Surfaces
- Contaminants
- Need for slip resistance
- Durability
- Toe protection
- Forefoot flexibility

Ergonomic Control Methods

- Localized pressure on body part - **hazards**
  - Using hands/knees as a hammer more than 10 times in 1 hour or more than 2 times per day (long-term)

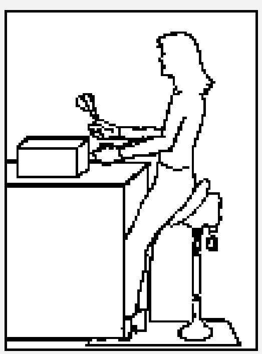






Ergonomic Control Methods

- Localized pressure on body part - **solutions**
  - Use tools with longer handles
  - Use tools with padded grips
  - Alternate between bending, kneeling, sitting, and squatting; use sit/stand stools or tables

Source: https://www.osha.gov/dsg/guidance/shipyard-guidelines.html

- Long extension handles for hand tools allow the operator to work standing instead of kneeling or crouching to use the tool.

Source: https://www.osha.gov/SLTC/etools/electricalcontractors/installation/using.html

- “Use tools with padded grips and handles that extend across the whole palm of the hand to minimize contact pressure.
- Ensure that tools such as screwdrivers have appropriately sized and shaped handles. Generally, handles should be about 1 1/2 inches to 3 inches in diameter. Triangular handles with rounded edges provide a better grip.”

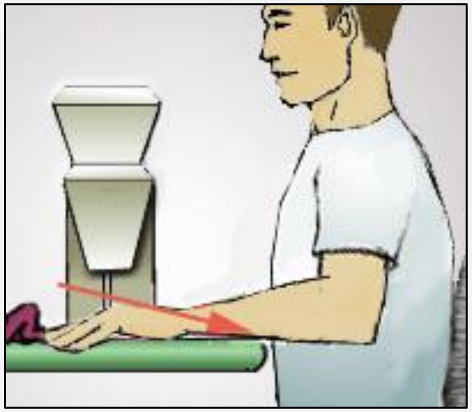
https://www.osha.gov/SLTC/etools/poultry/general_hazards/ergonomics.html#contact_stress

“General controls to reduce contact stress:

- Use electric or power tools, knives and scissors.
- Use spring-loaded scissors.
- Attached well-designed handles to tools.
- Wrap of coat tool handles and grips with cushioning material.
- Use palm pads.
- Use sit stand stools to reduce static loading on legs and back.
- Use shoes with thick or cushioned soles.”

Ergonomic Control Methods

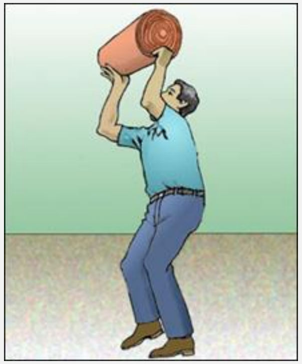
- Localized pressure on body part - **solutions**
  - Pad table edges or use tables/desktops with rounded edges
  - Use wrist rests, anti-fatigue mats, knee pads, shoe inserts or other items that reduce stress on body parts



Source: https://www.osha.gov/SLTC/etools/computerworkstations/components_desk.html

Ergonomic Control Methods

- Lifting objects - **hazards**
  - Lifting more than
    - 75 lbs. once/day
    - 55 lbs. ten times/day
    - 10 lbs. more than twice/minute or for more than 2 hours/day
    - 25 lbs. above shoulders, below knees, or at arms length more than 25 times/day



Ergonomic Control Methods

- Lifting objects - **hazards**
  - Heavy, frequent, and awkward lifting
  - Lifting more than twice per minute



Most people are aware that lifting heavy objects increases the risk for injury. The load on the low back when lifting something heavy can strain the muscles and damage the disks in your spine. The load can strain the muscles in the shoulders and upper back as well.

Ergonomic Control Methods

- Lifting - **solutions**
  - Managing for safer lifting
    - Plan lifts
    - Minimize lifting distances
    - Position materials to power zone levels
    - Avoid manually lifting/lowering loads to/from floor
    - Identify/reduce unstable or heavy loads
    - Reduce frequency of lifting and duration of lifting tasks
    - Provide clear access

Ergonomic Control Methods

Provide variable-height work surfaces.

Source: *Ergonomic Guidelines for Manual Material Handling* (2007), NIOSH, DHHS Publication No. 2007-131, http://www.cdc.gov/niosh/docs/2007-131/pdfs/2007-131.pdf

Use carts, hand trucks, hoists, conveyors or other mechanical assistance

Ergonomics at Work - Reducing pushing and pulling

Automated Cart Pusher

Using an automated cart pusher instead of having a person push multiple carts across a parking lot reduces wear on the body.

Ergonomic Control Methods

- Lifting - **solutions**
  - Employee guidelines for safer lifting
    - Stretch before lifting
    - Check for tags on loads
    - Test load for stability and weight
    - Plan the lift
    - Use proper lifting techniques –
      grip; two hands; smooth, even motions; load close to body; legs to push up and lift load; avoid twisting; alternate with less physically demanding tasks;
      rest breaks
    - Get assistance when necessary

Source: *Ergonomic Guidelines for Manual Material Handling* (2007), NIOSH, DHHS Publication No. 2007-131, http://www.cdc.gov/niosh/docs/2007-131/pdfs/2007-131.pdf

Ergonomic Control Methods

- Lifting - **solutions**
  - Use proper lifting techniques

Caution: This technique may be effective only if loads are small, light-weight, and can easily fit between the knees.

Keep the load close to your body and lift by pushing up with your legs.

Ergonomic Control Methods

- Lifting - **solutions**
  - Use proper lifting techniques

Lean the sack onto your kneeling leg.

Slide the sack up onto your kneeling leg.

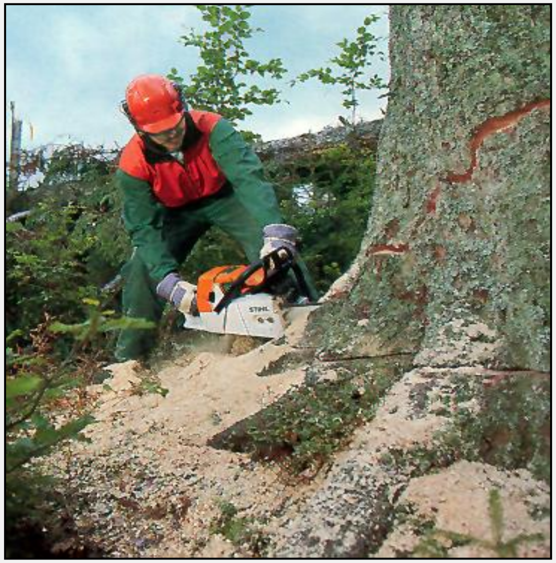
Slide the sack onto the other leg while keeping the sack close to your body.

As you stand up, keep the sack close to your body.

Ergonomic Control Methods

Vibration – **hazards**

- Moderate – more than 2 hours per day
- High – more than 30 minutes per day
- Prolonged



Source: https://www.osha.gov/SLTC/etools/woodworking/production_vibration.html

Ergonomic Control Methods

Vibration – **solutions**

- Use low-vibration tools and devices that may reduce vibration (tool balancers, extension handles, vibration isolators, damping techniques)
- Adequate rest periods, Gloves
- Rotate jobs
- Maintenance
- PPE **(Personal Protective Equipment)**

Source: https://www.osha.gov/dsg/guidance/shipyard-guidelines.html
- Use low-vibration tools that are specifically designed to reduce vibration.
- Use tool balancers (portable devices that support and positon tools), which may reduce exposure to tool vibration.

Source: https://www.osha.gov/SLTC/etools/woodworking/production_vibration.html
“Vibration isolators or damping techniques on equipment offer the most effective protection. Isolate machine vibrations from the surface if it is mounted or by use of vibration-isolation mounts. Vibrating panels of machine housings and guards may be controlled by use of damping materials applied to the panels. Felts, liquid mastics, and elastomeric damping sheets are effective damping materials. Determining the correct type and quantity of damping material to use for a particular machine is a complicated process and should be left to a knowledgeable person.”

Source: https://www.osha.gov/SLTC/etools/sawmills/vibration.html
- “Choose chain saws [tools] with the lowest vibration level suitable for the job.
- Allow adequate rest periods.
- Rotate jobs.
- Wear warm gloves when in cold temperatures, or anti-vibration gloves.
- Perform routine chain saw [tool] maintenance.
- Instruct workers not to grip saws too tightly.
- Remind workers that smoking decreases blood flow to fingers.
- Advise workers to exercise hands and fingers frequently to increase blood flow.”

Awkward postures happen when the work is:

Too low

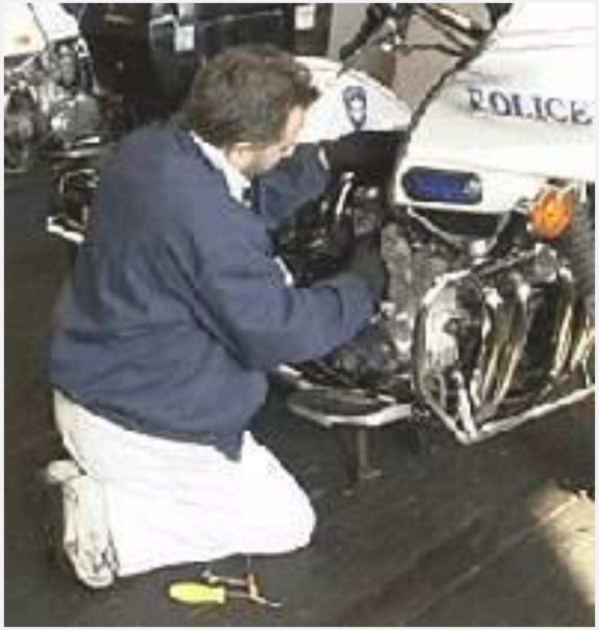
Too high

Too far away

Awkward Postures - Low work

Bending

Kneeling



Squatting

These postures are hard on the back and the knees

Reducing low work

- Raise and/or tilt the work for better access
- Use a stool for ground level work
- Use tools with longer handles
- Alternate between bending, kneeling, sitting, and squatting

Ergonomics at Work - Reducing low work

Raise the work

Reducing high work

- Use an elevated work platform or rolling stairs
- Use tools with longer handles
- Limit overhead storage to infrequently used items
- Bring the work down and tilt for easier access

Ergonomics at Work - Reducing high work

Use a tool with longer handles

Ergonomics at Work - Reducing high work

Fixture lift for overhead installations

REDUCING HEAVY LIFTING

Team Lifting

Team lifting works better on larger objects, such as the wallboard shown here.

There is a labor cost involved with team lifting, although in some jobs there is always another person around out of necessity.

REDUCING AWKWARD LIFTING/REACHING

- Remove Obstacles
- Slide Closer
- Reduce Shelf Depth
- Reduce Package Size
- Use Mechanical Assistance
- Team Lifting

REDUCING AWKWARD LIFTING/REACHING

Reduce Package Size

The drawings show the difference between lifting a large box with many items in it versus lifting a smaller box with fewer items in it. Not only will this reduce the weight, but it will also reduce the reach necessary to pick up the box. Costs to implement this idea will vary.

If you're the customer, you can request smaller packaging from the supplier and probably pay a little more per item due to their increased packaging costs.

REDUCING AWKWARD LIFTING/REACHING

Reduce Shelf Depth

The examples shown are designed to fit into existing standard racks, so new gravity flow racks won't need to be purchased and installed.

The costs of these systems range from about $60 per lane to a little over $200 per lane depending on depth and width of lanes.

REDUCING AWKWARD LIFTING/REACHING

Reaching Above Shoulders

Use Mechanical Assistance

The device shown is a stacker, which is like a hand truck with a hand-cranked winch to move the platform up and down so that loads can be mechanically raised to the height they are shelved or removed from shelves.

REDUCING AWKWARD LIFTING/REACHING

Reaching Above Shoulders

Use Mechanical Assistance

This example shows using a carton clamp on a forklift to split/combine two halves of a stack of bins, rather than un-stacking/stacking the top layers over shoulder height.

REDUCING AWKWARD LIFTING/REACHING

Reaching Above Shoulders

Use a Rolling Stair

This is a simple solution, although safety is a concern when using anything like this. Safety rules don’t allow going up and down ladders while carrying loads, so a rolling stair or “safety ladder” (50 degree slope or less) is required.

An added advantage is that you can put the load down before going up or down the steps.

REDUCING AWKWARD LIFTING/TWISTING

- Use Conveyors
- Provide More Space
- Arrange Storage

REDUCING AWKWARD LIFTING/TWISTING

Use Conveyors

Conveyors such as this one are especially useful when changing directions, to help avoid twisting. This picture shows a gravity conveyor used to unload trucks in a shipping department. It allows the receiver to bring the boxes over to the computer to scan in the information and inventory the contents. The boxes can then be slid directly onto carts to be put away. Lifting only needs to occur twice, once to take the box from the truck and place it on the conveyor, and once to put the box away. This conveyor set up (gravity rollers) costs about $600.

REDUCING AWKWARD LIFTING/TWISTING

Rearrange Storage

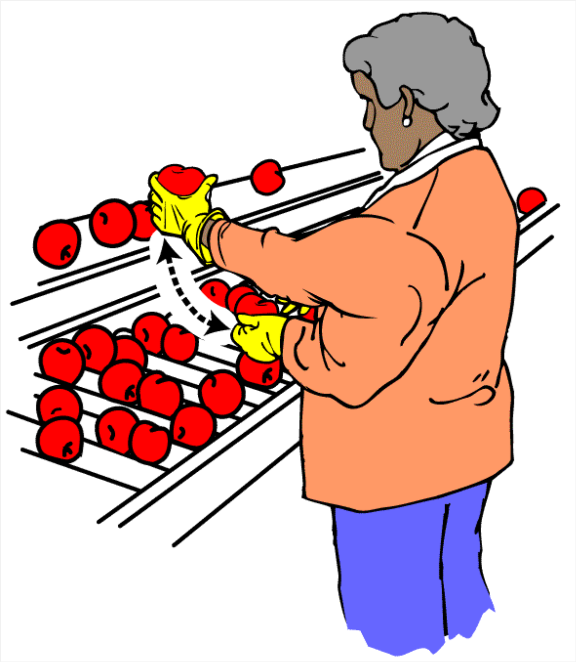
This example shows how raising the height of the upper racks can provide more room to get at products on the lower racks. This may involve installing additional racks to make up for the loss in storage space. Otherwise, if the facility can get by with the racks they currently have, then it's just labor costs to rearrange the storage.

Ergonomics at Work - Reducing reaching

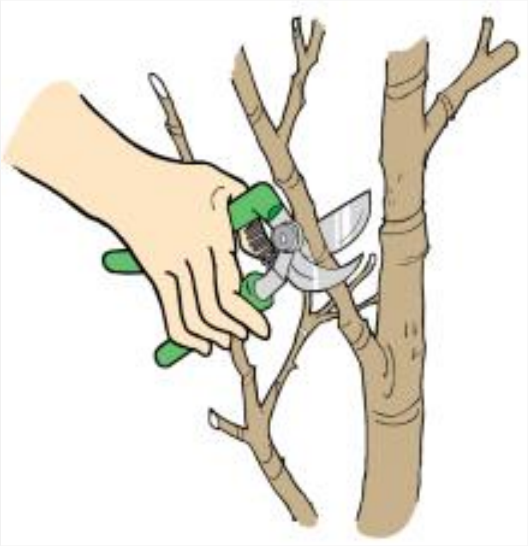
Gravity Feed Racks

Hand Intensive Work

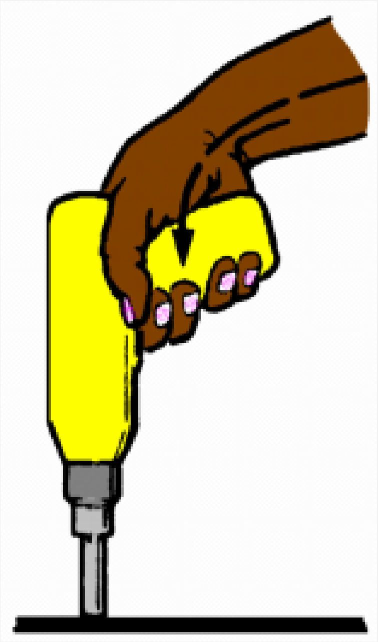
Repetitive motions



Gripping
Pinching



Bent wrists



Reducing repetition

- Arrange work to avoid unnecessary motions
- Let power tools and machinery do the work
- Spread repetitive work out during the day
- Take stretch pauses
- Rotate task with co-workers if possible
- Change hands or motions frequently

Hand Intensive Work – Gripping

Gripping with the whole hand can be a problem if what you are gripping is relatively heavy, such as a tool that weighs more than 10 pounds. Lighter objects may also require a lot of grip force, in other words, squeezing with a force of more than 10 pounds. One example is the cake decorator using a pastry bag filled with thick frosting.

Other factors

Your grip strength decreases when you:

- Bend your wrists
- Pick up slippery items
- Wear poorly fitting gloves
- Have cold hands

Reduce grip force

- Grip with the whole hand, not just the fingertips
- Pick up smaller loads
- Use carts or handtrucks instead of carrying
- Keep tools in good working order
- Use lighter tools or tool balancers
- Use two hands

Ergonomics at Work - Reducing gripping

Tool Balancer

Ergonomics at Work - Reducing gripping

Use a clamp or vise to hold parts

Ergonomics at Work - Reducing bent wrists

Re-orient the work

Hand Intensive Work – Combinations

Risk of injury goes up as you combine factors

Risk

Repetition +
Gripping or Pinching +
Bent wrists

Repetition +
Gripping or Pinching

Repetition

Intensive keying

Reducing intensive keying

- Use macros for common functions
- Spread keyboard work throughout the day
- Take stretch pauses
- Improve your posture and move around as much as possible

Work station redesign

- Reduce static loading
- Raise / lower working height
- Remove hard / sharp edges
- Provide mechanical advantages
- Insulate heat / cold
- Provide seating / support
- Improve material orientation
- Improve layout

Five key points to remember

1. Ergonomics can help you on your job
2. WMSDs can happen in jobs with risk factors
3. Risk factors can be reduced and WMSDs prevented
4. Reporting symptoms early is important
5. You can help your company put ergonomics changes into place

Ergonomic Control Methods

Environmental ergonomic hazards:

- Amplify/increase risk of MSDs
- Examples
  - Hot weather
  - Cold weather – affects worker coordination and dexterity
  - High-temperature indoor (steam rooms, attics)
  - Cold-temperature indoor (walk-in freezers, cold process rooms)
  - Low visibility

Employer/Employee Requirements

General Duty Clause

- **Each Employer:**
    1. Shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;
    2. Shall comply with occupational safety and health standards promulgated under this Act.
- **Each Employee:**
    1. Shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct.

Employee/Employer Requirements

Report signs or symptoms if:

- Pain is persistent, severe or worsening
- Pain radiates
- Symptoms include numbness or tingling
- Symptoms keep you from sleeping at night
- Fingers blanch or turning white

Employee/Employer Requirements

Getting involved:

- Look at jobs
- Come up with solutions
- Work with solutions
- Take part in training
- Take responsibility for changing the way you do your job
- Help to make sure efforts are successful

Five Key Points to Remember

- Ergonomics can help you on your job
- WMSDs can happen in jobs with risk factors
- Risk factors can be reduced and WMSDs prevented
- Reporting signs and symptoms early is important
- You can help your company put ergonomics changes into place

Knowledge Check

1. Ergonomics is the science of ___.
   a. designing the job to fit the worker
   b. fitting the worker to the job
   c. lifting injuries
   d. safety and health

Answer: **a. designing the job to fit the worker**

Knowledge Check

2. MSDs account for approximately ____ of all injuries and illnesses.
   a. 1%
   b. 10%
   c. 33%
   d. 54%

Answer: **c. 33%**

Knowledge Check

3. Which of the following is an example of an ergonomic risk factor?
    a. Neutral postures
    b. Rest
    c. Repetition
    d. Personal protective equipment

Answer: **c. Repetition**

Knowledge Check

4. Ergonomic hazards can be prevented or reduced by which of the following control methods?
   a. Engineering controls
   b. Proper work practices/administrative controls
   c. Personal protective equipment
   d. All of the above

Answer: **d. All of the above**

Knowledge Check

5. What are the risks of MSDs?

There are 5 common ergonomic hazards that may occur in work activities.

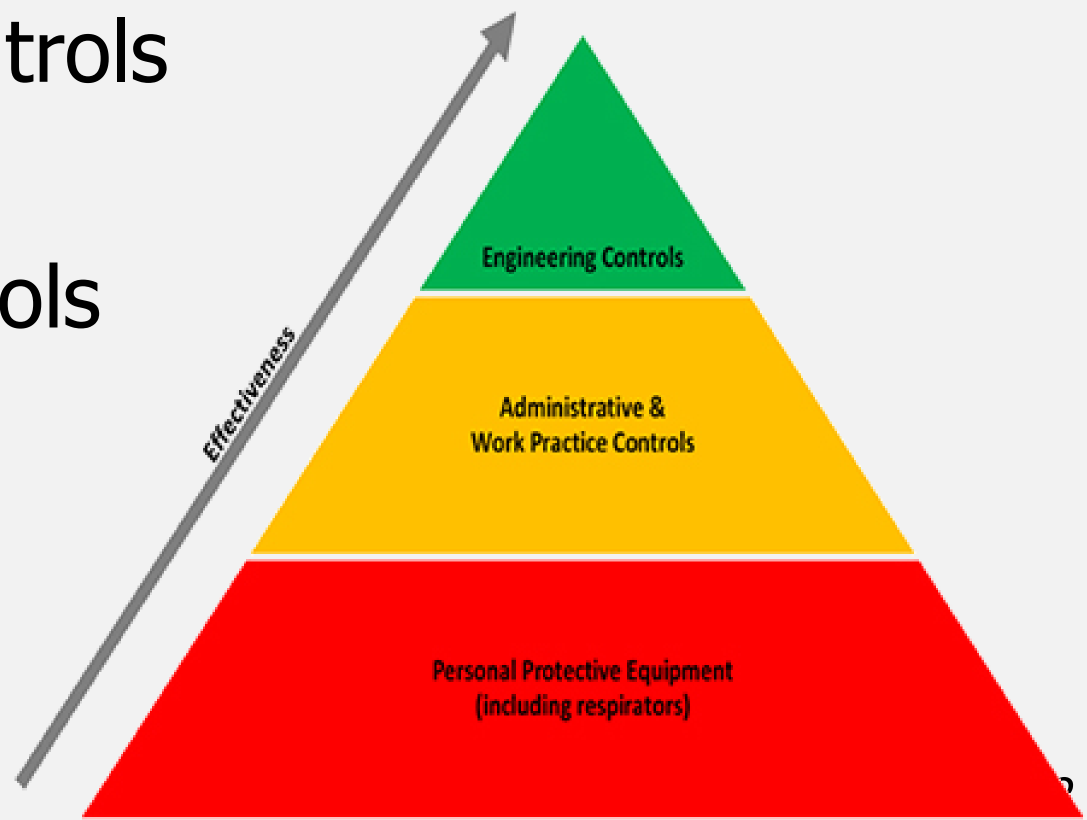
Answer:

- **Repetition- involves doing the same task repeatedly that uses the same muscles over and over.**
- **High Force- using high muscle power during activities such as heavy lifting, pushing items or gripping tools.**
- **Awkward Postures- working with your body held in a poor position for a long time.**
- **Contact Stress- when pressure from an object is pushed on the soft body tissues (i.e. tool handle).**
- **Hand-Arm Vibration-vibration that enters the body from a power tools or equipment.**

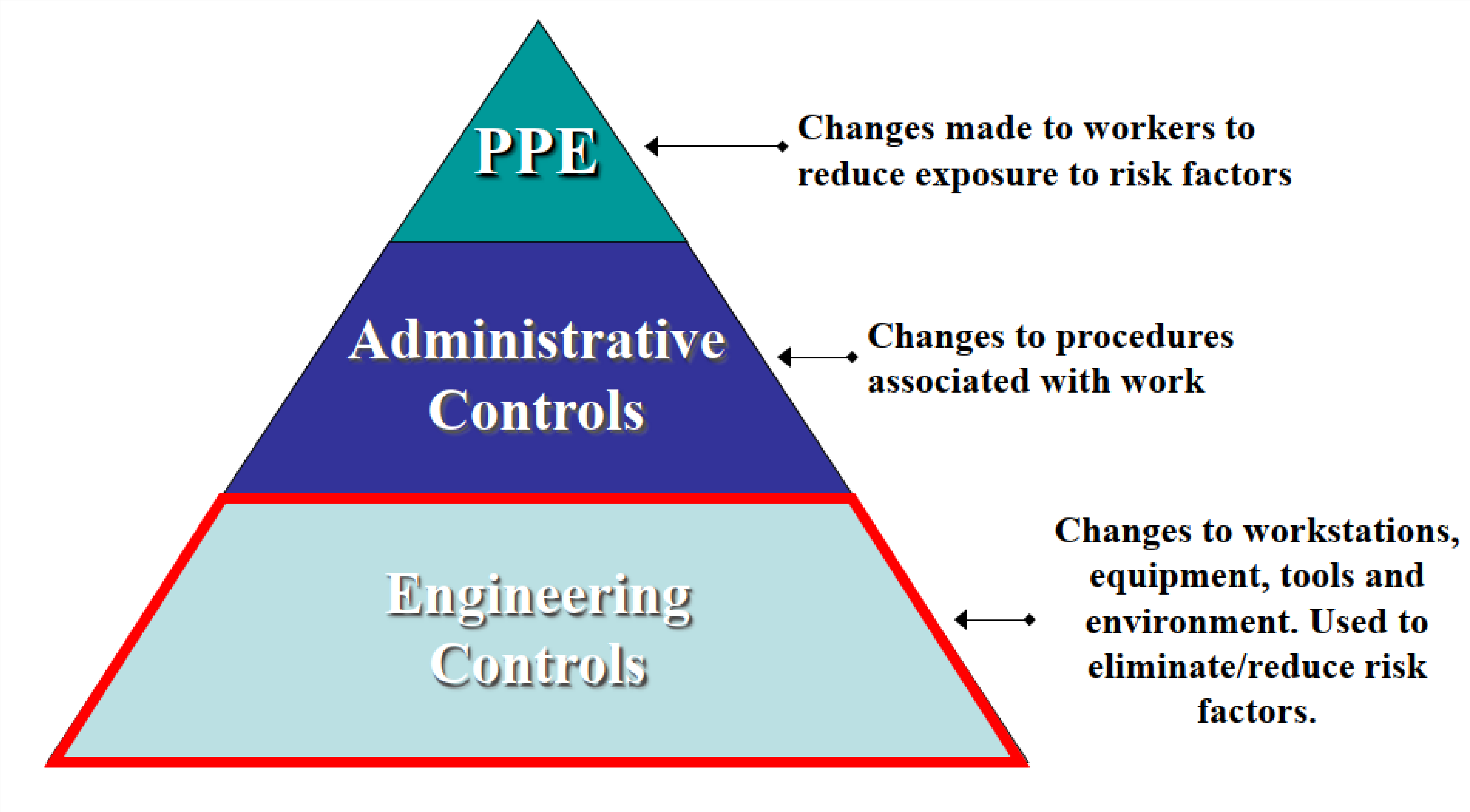
Trade	*Hazards* High Force	Awkward Postures	Repetition	Contact Stress	Hand-Arm Vibration
Carpenter - Drywall	Hands: Gripping a utility knife with a dull blade to cut drywall. Whole body: Lifting a drywall sheet > 100 lbs by yourself.	Operating a screw gun overhead with the arm fully extended and the wrist bent.	Driving screws into drywall every couple of seconds for 2 hours without brief rest periods.	Repeatedly using your palm to hit the blunt edge of a metal stud into place.	During prep work, using a concrete saw to cut into the floor for more than 2 hours in a shift.
Floor Layer	Hands: During prep, gripping a hand scraper to scrape stuck VCT and glue off a concrete floor. Whole body: Push/pulling a pallet of ceramic tiles using a pallet jack with bad wheels.	Spreading adhesive using a hand trowel with the arm fully extended out to the side and the wrist bent.	Using the same arm motion repeatedly to spread floor leveler over an open floor for two hours without brief rest periods.	Kneeling on concrete without wearing kneepads.	Operating a walk-behind electric floor scraper that shakes the hands and arms for more than 2 hours in a shift.
Sheet Metal Worker	Hands: Gripping snips to cut thick gauge metal. Whole body: Lifting a long piece of duct alone without the use of a handling device.	Prepping duct parts on the floor while bending the back and reaching to work on them.	Shop work: Repeated, similar motions during deburring that occurs for 2 hours or more without brief rest periods.	Repeatedly using your palm to hit/ assemble metal pieces together.	Operating a hand-held hammer drill to drill holes in concrete for more than 2 hours in a shift.

WHAT CAN WE DO?

- Administrative controls
- Work practice controls
- Engineering controls



Personal Protective Equipment (use protection to reduce exposure to ergonomics-related risk factors)



https://miningquiz.com/pdf/PDF_categories.htm

ADMINISTRATIVE CONTROLS

= procedures and methods that significantly reduce daily exposure to hazards

- Employee rotation/job task expansion
- Physical adjustments to the work pace
- Adjust the Work Pace
- Job rotation
- Redesign of work methods
- Alternative tasks
- Breaks (Schedule More Breaks for Rest and Recovery)
- Providing Training

1. Employee rotation/job task enlargement-if possible rotate employees between job tasks so that an employee is assigned to perform one task then moved to another. Or enlarge the employees tasks so the employees have the opportunity to perform a different task.
2. Adjust work pace- hard to do. But if possible slow it down a little. Affects piece work more than an office situation. Make sure you work at a reasonable pace, don't stress yourself.
3. Redesign how the work is performed. Another procedure. Is there a better way to do the task with less stress, strain, is there a tool or piece of equipment that could be used to help perform the task.
4. This ties in with the first control mentioned. Whenever possible have employees alternative their tasks frequently throughout the day. Rotate heavy and/or repetitive tasks with lighter, less repetitive tasks. Example is break up typing with filing. Break up use of a jackhammer with moving materials. Be aware that even tasks such as manual stapling, sorting through large volumes, and mail sorting were repetition and awkward positions may contribute to repetitive motion injuries (MSDs).
5. Breaks-Encourage employees to change position, stand up or stretch whenever they start to feel tired. (We will talk about stretching exercises later in the program.) Remember the short discussion on biomechanics and the static vs the dynamic work positions and that muscles fatigue easier when held in the same position for extended periods of time. Encourage motion rather than static positions. It is recommended that you take 1 or 2 minute breaks every 30 minutes and 5 minute breaks every hour when performing stationary type work. But remember a "break" could be doing another activity rather than just "taking a break." Make a phone call, file something, or other activity. It is also recommended that every few hours, you try to get up and move around.

Implementing Controls

- Designate the Personnel Responsible
- Create a Time-table
- Consider the Logistics Necessary for Implementation

WORK PRACTICE CONTROLS

- Safe & proper work techniques & procedures
- Training
- Physical conditioning period

1. Safe and proper work techniques and procedures for performing the job tasks that are understood and followed by managers, supervisors, and employees. **The work techniques could include proper positions and angles when sitting at your computer station to standing and performing tasks.**
2. Training recognition of hazards and work techniques that can reduce exposure or ease task demands and burdens. Use written procedures to train such as the JSA. Workers acquire certain behaviors over a long period of time. This affects the way they work, their posture, lifting techniques, etc and could create potentially hazardous situations. Regular ongoing training is an essential part of the program.
3. Conditioning period for new or reassigned employees to learn the work techniques and procedures. Supervise the employees performing the tasks to ensure understood the training and are performing correctly. If not provide additional training.

ENGINEERING CONTROLS

= implement physical change to the workplace, which eliminates/reduces the hazard on the job/task

- Workstations
- Tools/equipment
- Facilities
- Work methods
- Materials
- Processes

- Preferred method for controlling hazards
- Make physical changes to tasks
- Act on the source of the hazard
- Control employee exposure
- Do not require “self-protective” action


H

Workplace Examples	
Engineering Controls (implement physical change to the workplace, which eliminates/reduces the hazard on the job/task)	•Use a device to lift and reposition heavy objects to limit force exertion •Reduce the weight of a load to limit force exertion •Reposition a work table to eliminate a long/excessive reach and enable working in neutral postures •Use diverging conveyors off a main line so that tasks are less repetitive •Install diverters on conveyors to direct materials toward the worker to eliminate excessive leaning or reaching •Redesign tools to enable neutral postures

Strategies for Job Design

- Change the Way Materials, Parts, and Products Can Be Transported (e.g., use mechanical assist devices rather than manual handling)
- Change the Process or Product to Reduce Risk Factors (e.g., maintain the fit of plastic molds to reduce the need for manual removal of flashing, etc.)

Strategies for Job Design

- Modify Containers and Parts Presentation (e.g. height adjustable material bins, etc.)
- Change Workstation Layout (e.g., use height adjustable workbenches, etc.)
- Change the Way Parts, Tools, and Materials are to be Manipulated (e.g., use fixtures to hold workpieces, etc.)

Strategies for Job Design

- Change Tool Designs (e.g., pistol handle grips for knives to reduce wrist deviations, etc.)
- Change Assembly Access and Sequence (e.g., remove physical and visual obstructions, etc.)

TOOLS

- Use of Force or of grip-strength
  - Longer/shorter and thicker/thinner handles
- Repetitive motion
  - Ratcheting mechanism or gears
  - Power tools
    - Electric stapler
    - Electric knife
    - Spring-loaded returns

TOOLS CONT.

- Awkward positions
  - Bent or curved handles
  - Extensions or add-ons
  - Headphones
  - Support equipment overhead
  - Step stool
- Forceful exertions
  - Soft-touch keyboards/buttons
  - Lifting devices

TOOLS CONT.

- Static positions
  - Anti-fatigue mats
- Vibration
  - Anti-vibration materials
  - Anti-vibration mounts/handles
  - External support
  - Anti-vibration gloves

FACILITIES

- **Temperature**

Elevated temperatures and humidity can be harmful. Low temperatures can reduce finger flexibility and accuracy. Keep in mind that temperature can be affected by several factors including type of work, clothing and heat sources, and amount of airflow.

FACILITIES

- **Noise**

Excessive noise levels above 90 decibels (dBA) and noise peaks above 100 decibels cause headaches and increases blood pressure, muscle tension and fatigue. High exposure over a long period of time causes deafness and other audiological disorders. Short term exposure causes irritability and distraction.

EYE

- Eye comfort exercises
  - Blinking
  - Yawning
  - Focus change

While seated, brace elbows on the edge of the desk
Let weight fall forward
Cup hands over eyes and close eyes
Inhale slowly through nose and hold for 4 seconds
Continue deep breathing for 15-30 seconds

Ergonomics Applies to…

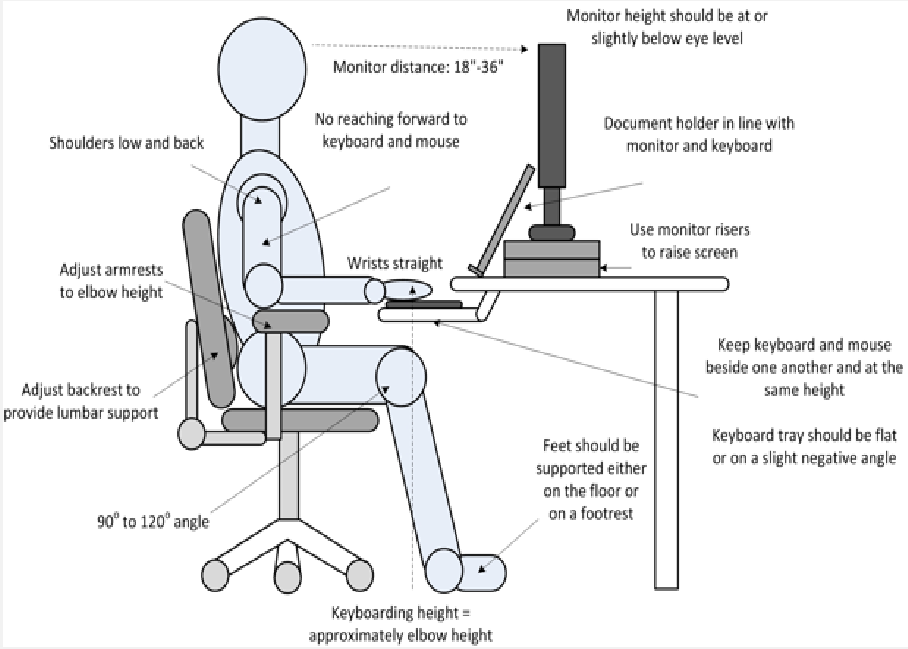
- **Workstation Design—(desks, chairs, space, layout)**
- **Work Postures (sitting, standing, reaching, lifting)**
- **Work Organization (Pace, Breaks, Variety)**
- **Tools, Equipment, and Furniture Design---(body size, height, gender, promoting neutral postures, reduced vibration, exposure to acceptable lighting, noise, temperature)**
- **Manual Materials Handling—(lifting, lowering, pulling, pushing, carrying and holding materials)**
- **Work Environment—(ventilation, noise, temperature & humidity, lighting and vision)**

BENEFITS OF ERGONOMICS

- Decreased injury risk
- Increased productivity
- Decreased mistakes/rework
- Increased efficiency
- Decreased lost work days
- Decreased turnover
- Improved morale

Laptop Computers and Mobile Devices

- Initially designed for short term use; now used frequently
- Issues stem from proximity of laptop (and similar mobile devices) monitor & keyboard
  - to position the laptop monitor at the right height for your back and neck, you have to lift your arms and shoulders too high, causing shoulder and neck problems
  - to position laptop keyboard at the best height for your arms and shoulders, you must hunch your shoulders and neck to see the monitor



Laptop Computers and Mobile Devices

- Advice is similar to that of standard workstations
  - Use a correctly set-up desktop computer instead of a laptop / mobile device as often as you can
  - Use peripheral equipment, such as a docking station, separate keyboard, mouse and laptop stand
  - Take frequent breaks
  - Carry your laptop in a backpack or in wheel-along luggage

WORK-RELATED UPPER LIMB DISORDERS (WRULDs)

- Increasing occurrence of WRULDs
- Risk Factors:

Physical Risk Factors	Psychosocial Risk Factors	Individual Risk Factors
Repetition	Job demands	Age
Force	Job control	Gender
Posture	Social relations at work	Socioeconomic status
Vibration		Pre-existing musculoskeletal disorders

Ergonomics design principles
EN 614-1, EN 614-2 and EN ISO 6385

Ergonomics in workplace design: good for health and good for business!

By application of ergonomics in workplace design, the production systems and workplaces can be improved **both for the worker and for the organization.**

To summarise, the following outcomes are typically achieved:

- Better **satisfaction, motivation and commitment** of the worker
- Lower rate of **accidents** and fewer **sickness absences**
- **Less disturbances and losses in production** due to human error
- Better **quality**, less careless work
- **Fluent operation**, the right operations in the easiest way
- **Less need for corrections** later: Less costs of late changes

How Ergonomics Can Help

EMPLOYEE:

✓Fewer injuries

✓Improved Health & Safety

✓Reduce absenteeism

✓Lower worker turnover

✓Fatigue

✓Quality of life

EMPLOYER:

✓Increase in work quality

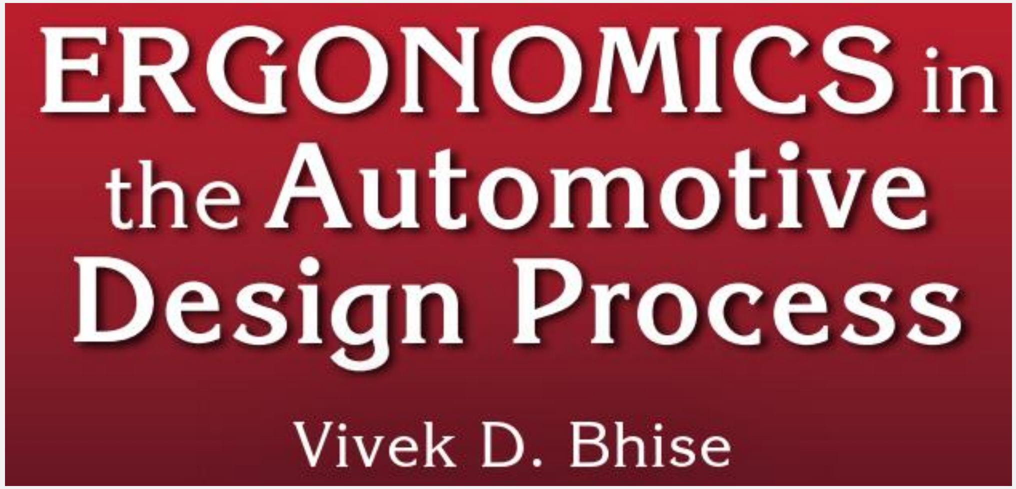
✓Morale improves

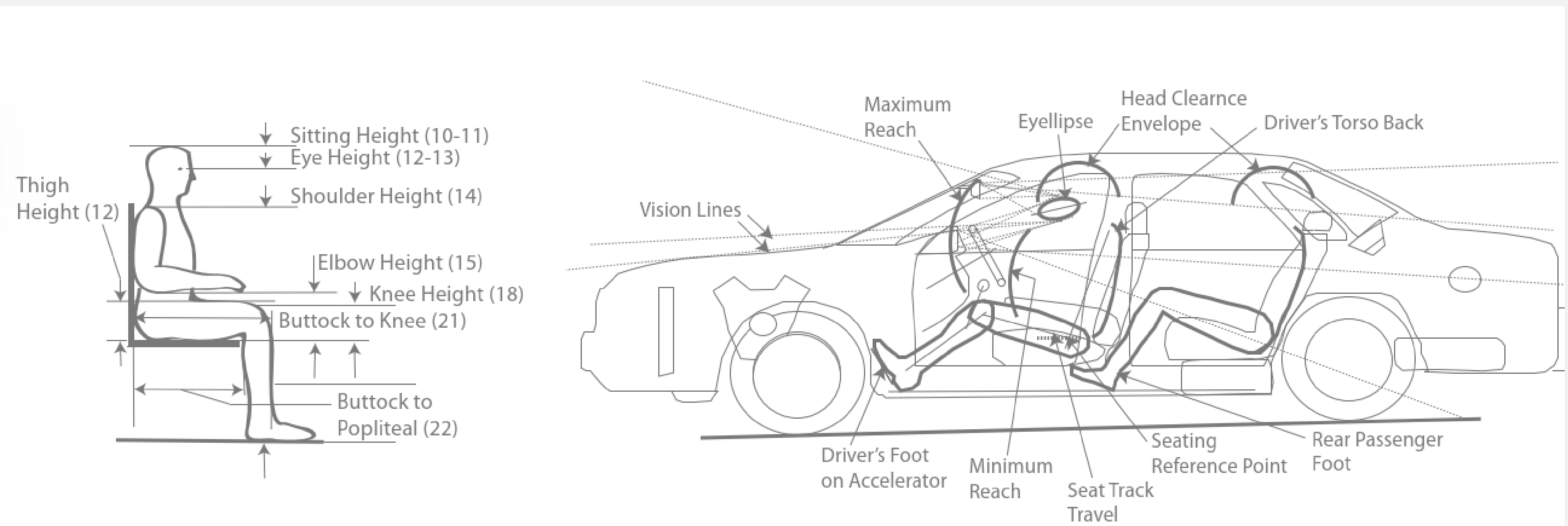
✓Increase productivity & efficiency

✓Lowered workers' compensation rates

✓Less likelihood of OSHA fines

CAR ERGONOMICS





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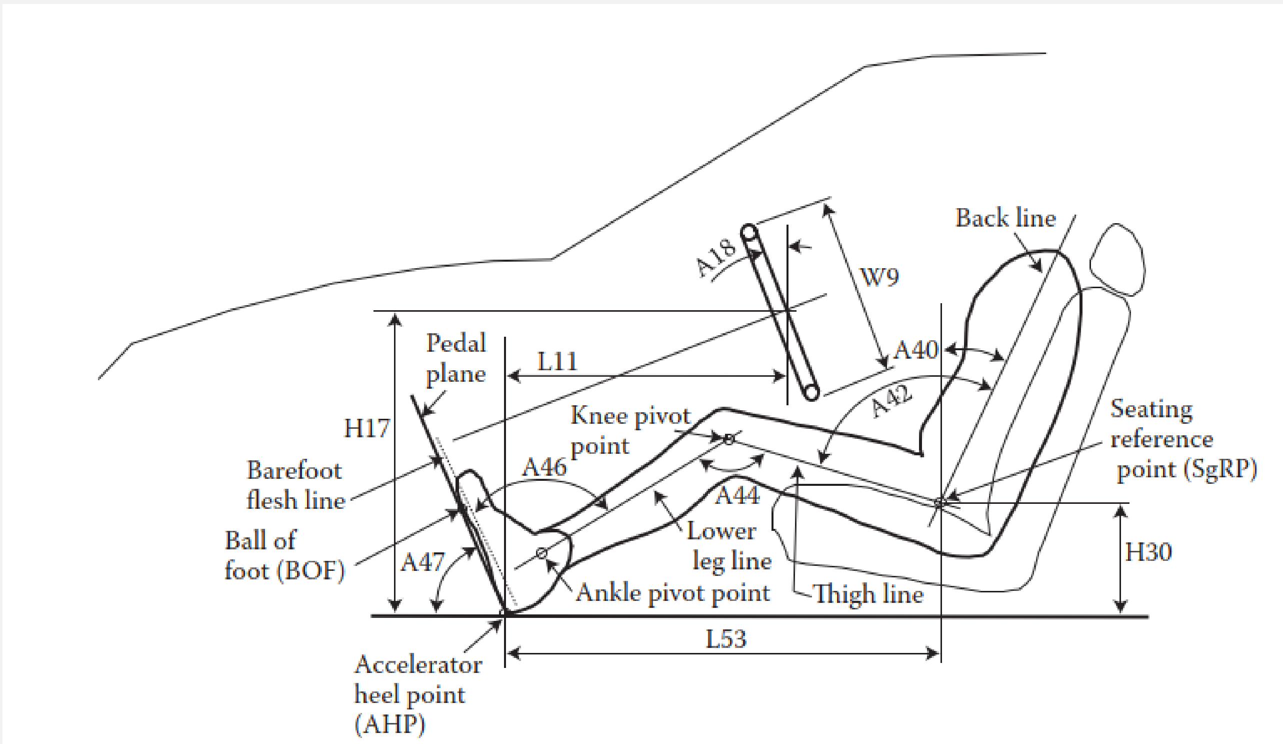


THE SAFETY AT WORK IN EXPERIMENTS OF POLYMERS AND COMPOSITES

Safety at work during special tests for polymers – polymer fibres and long-fibre composites at on selected laboratory test machines and apparatus.

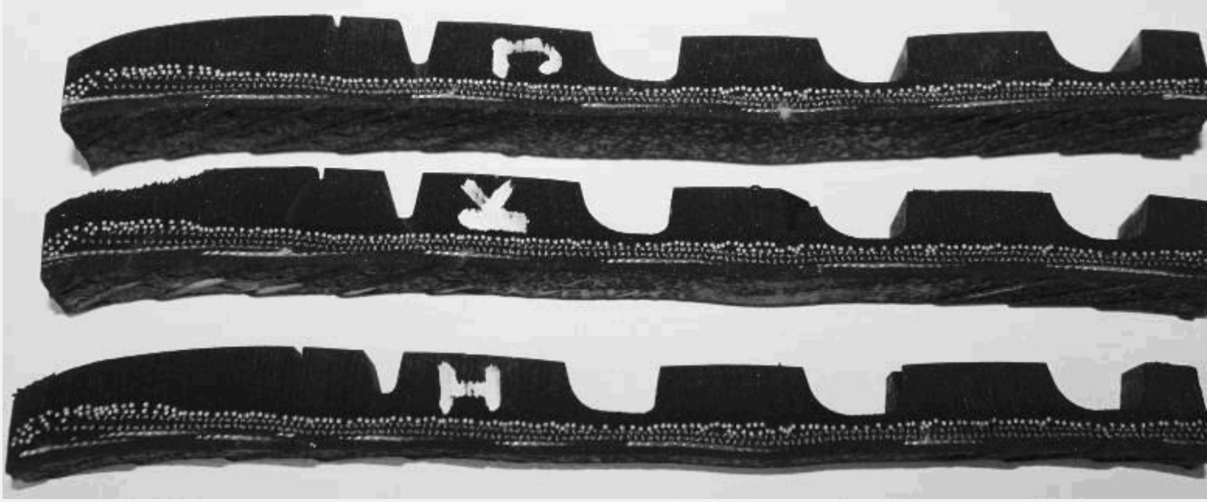
The safety and warning information on injuries are provided on these devices. High temperatures are applied to the test equipment, and some have moving parts. Therefore, the operators have to be very careful during testing, measurement and production of test samples too.

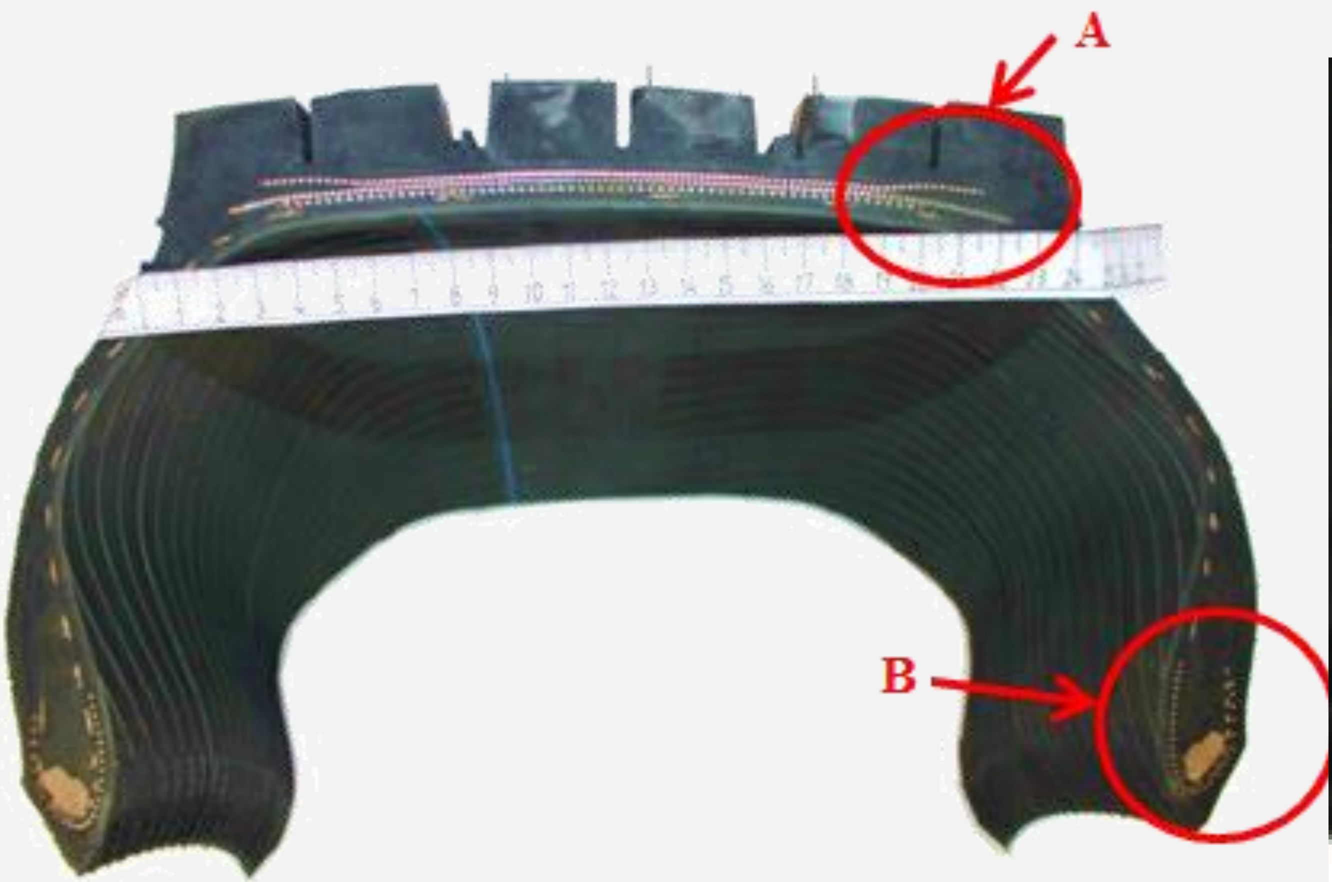
SAFETY DURING

SAMPLE PREPATION

SAMPLES OF TIRE-CASINGS AND COMPOSITES WITH STEEL CORDS

sharp edges of steel cords after waterjet cutting





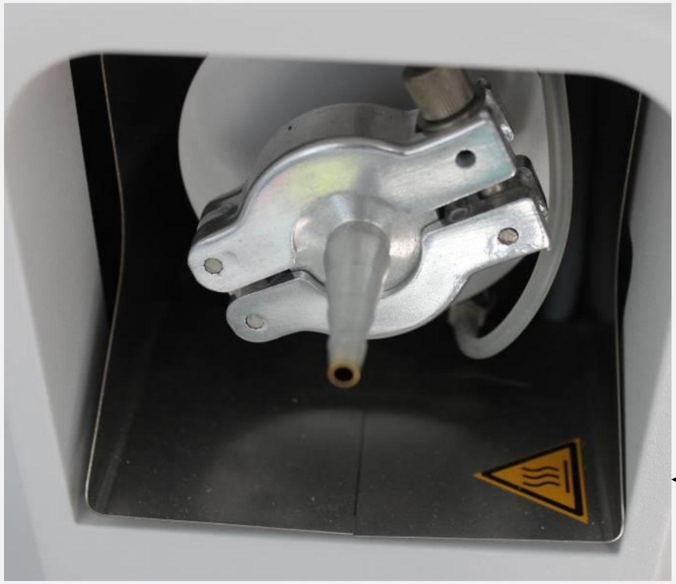
Safety at work at

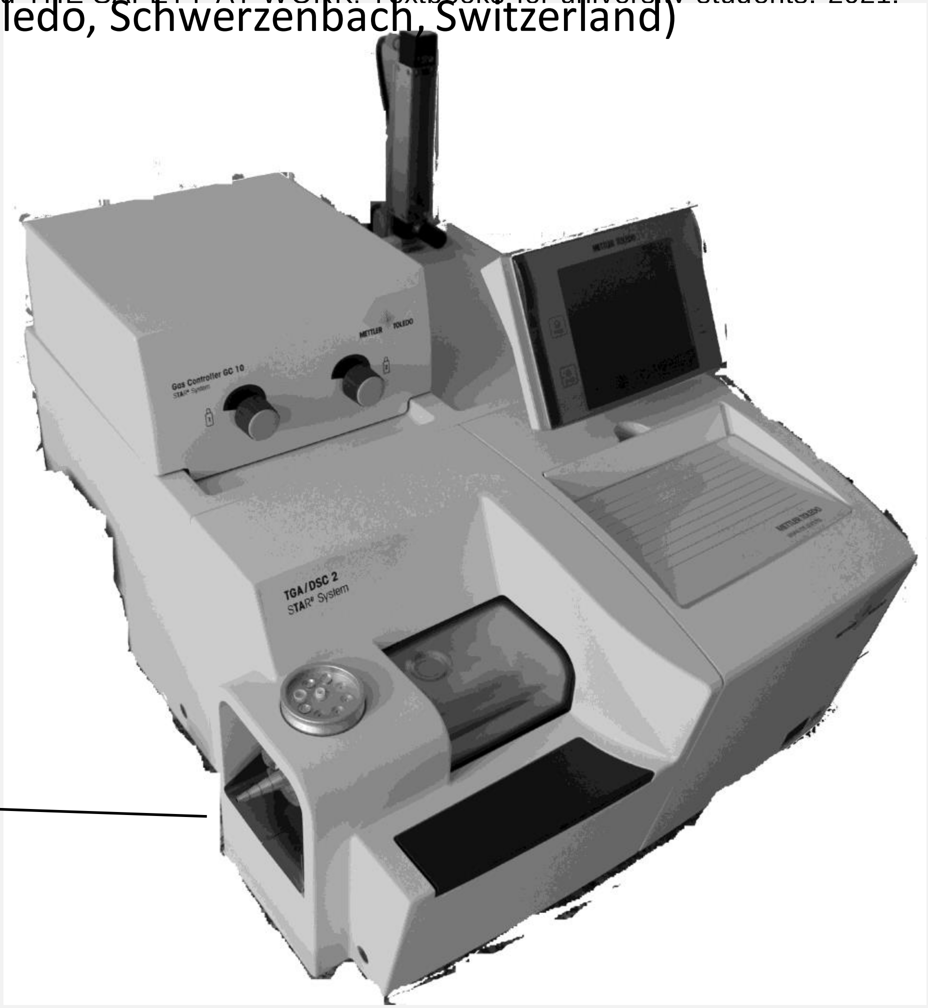
TGA/DSC ANALYZER

to find the crystallinity temperature of polymers

TGA/DSC 2 HT/1100 STARe System (Mettler Toledo, Schwerzenbach, Switzerland)

hot part on the analyzer





During measurements, there is a hot part on the analyzer with pictogram because temperature range is from 30 to 600 °C.

The operator must be cautious during measurements and when changing the test samples.

Safety at work at

PLASMA REACTOR

for surface modification of polymers

Plasma reactor KPR 20 produced by Research Institute for Man-Made Fibers (Svit/Slovak Republic)

Generating homogenous plasma under atmospheric pressure = low-temperature plasma

can be used for continuous double-sided surface modification of thin flat materials (polymers, textiles, metals, glass) and composites (foils with thickness of 50 μm – 0.5 mm, thin flexible polymeric flat plates with thickness of 0.5–1 mm and thin textile materials as well as cords with diameter of 0.1–0.5 mm).

Plasma action on nanometric level on polymer fibre surface allows to create quite a new class of innovative materials and their use.

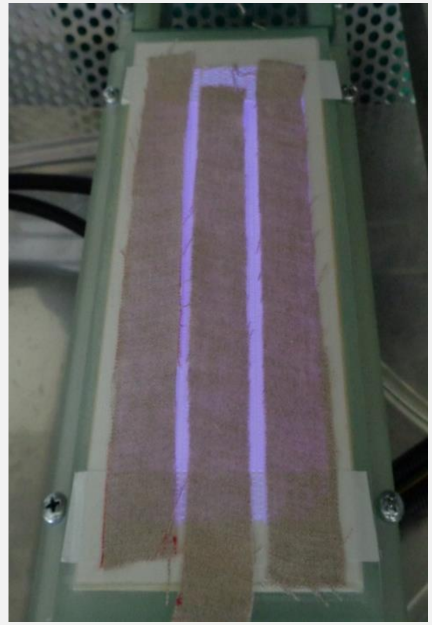
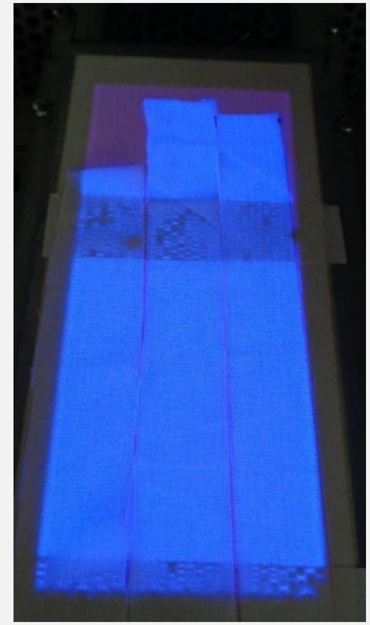
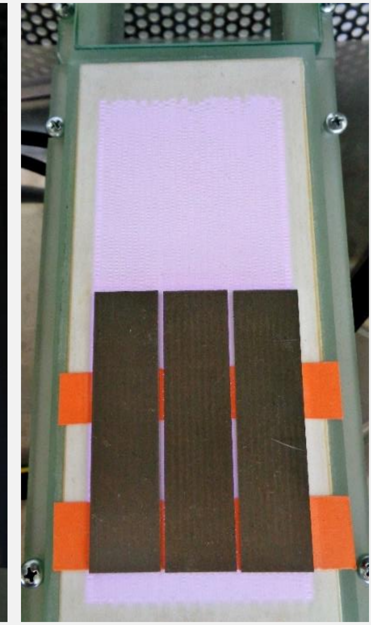
Applications: Effective hydrophilization and activation of the surface of polypropylene fabrics, polymer films, metals, glass...

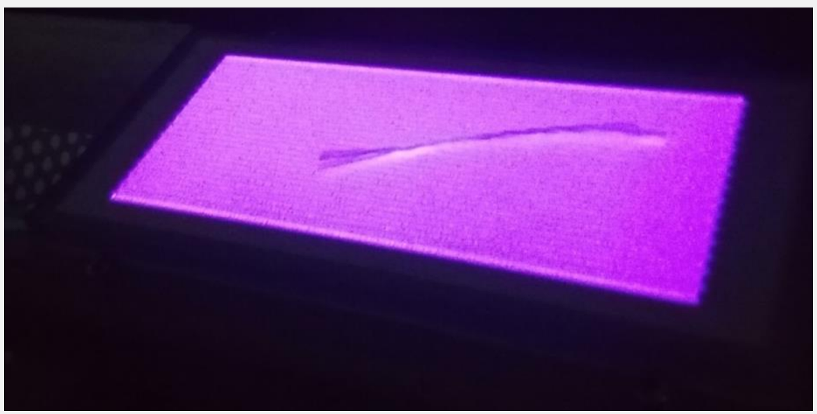
Surface treatment of PP foils before printing or dyeing

Adhesion improvement of PES cords to rubber in tyres

Surface cleaning.






Character of Materials:
Polymers, textiles, metals, glass, composites

Extremely high power density of plasma up to 100 W/cm^{-3} allows short plasma exposure times and thus high speed processing.

Surface activation of low-temperature plasma by diffusion coplanar dielectric barrier discharge on the fibre surface – curved electrode

- Depth of generated plasma: 0.3 mm
- Operation: in the atmospheric air
- Time of plasma surface activation: 3 – 120 s
- Power: 400 W

Contact with the human body and the plasma electrode system is not dangerous. During the plasma treatment the ozone is formed, but ozone is exhausted.

Plasma reactor has several drawbacks as unprotected rotating parts of the equipment.

There is possibility of electrostatic charges and possibility of improper use of electrical wiring.

The on/off (total stop) button is only on the control panel.

There is possibility of burning during operation of the device. It has a high sound level.

Safety at work at laboratory for the production of elastomer and composite samples

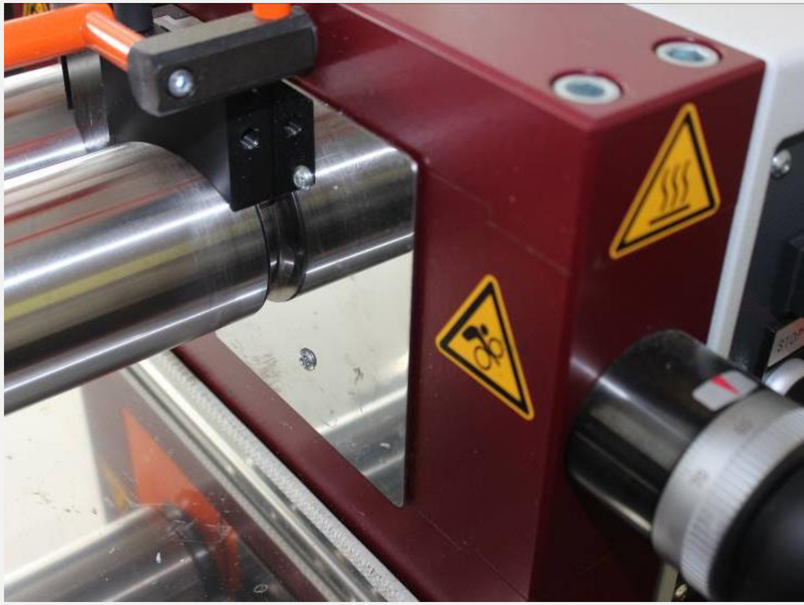
The laboratory consists from:

- torque rheometer for mixing and extruding elastomers,
- homogenization machine,
- vulcanization hydraulic press,
- pneumatic hollow die punch.

The torque rheometer Brabender Plastograph® EC plus

There is a very hot chamber (working temperature to 500 °C) with rotation parts with revs up to 150 min^{-1}. During machine running the operator must be very careful. Risk of burns.

Homogenization machine with detail of rotating heated rollers and hot parts

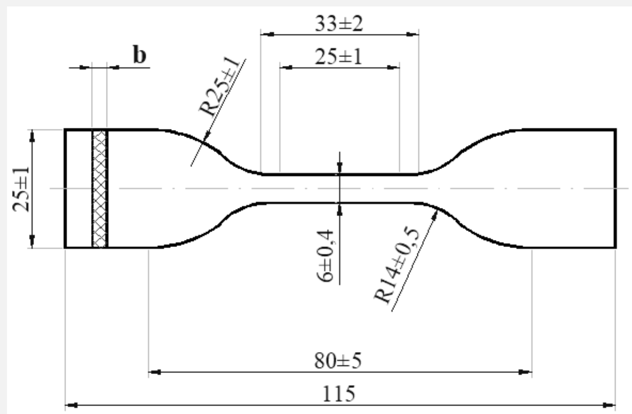


The temperature is changed during homogenization process (maximum temperature is 150 °C). There are very hot rotating parts – two heated rollers. In addition, hair and clothing of operator may be pulled in.

Vulcanization hydraulics press LabEcon 600

The maximum temperature is 300 °C. In addition, emergency buttons are located. The press is fully automatic and the operator is protected by a safety cover.

Pneumatic hollow die punch Inston



The control buttons for run of device are located on both sides of the device and must be pressed by the operator with both hands at the same time. Thus, the moving part cannot come into contact with the operator's fingers.

Safety at work during CYCLIC LOADING TESTS OF COMPOSITES OR TEXTILE CORDS with hybrid chamber

The part deals with safety at work during cyclic loading tests of composites on testing machine with hybrid temperature-humidity chamber, high speed tests of tires for passenger cars on dynamic test machine.

The tests of cyclic loading of these composites are requested for the verification analyses between tests and computational modeling of composite parts of passenger cars and tires too. The optimization of an angle of textile reinforcement in composites is possible on the basis of the results from the test of cyclic loading.

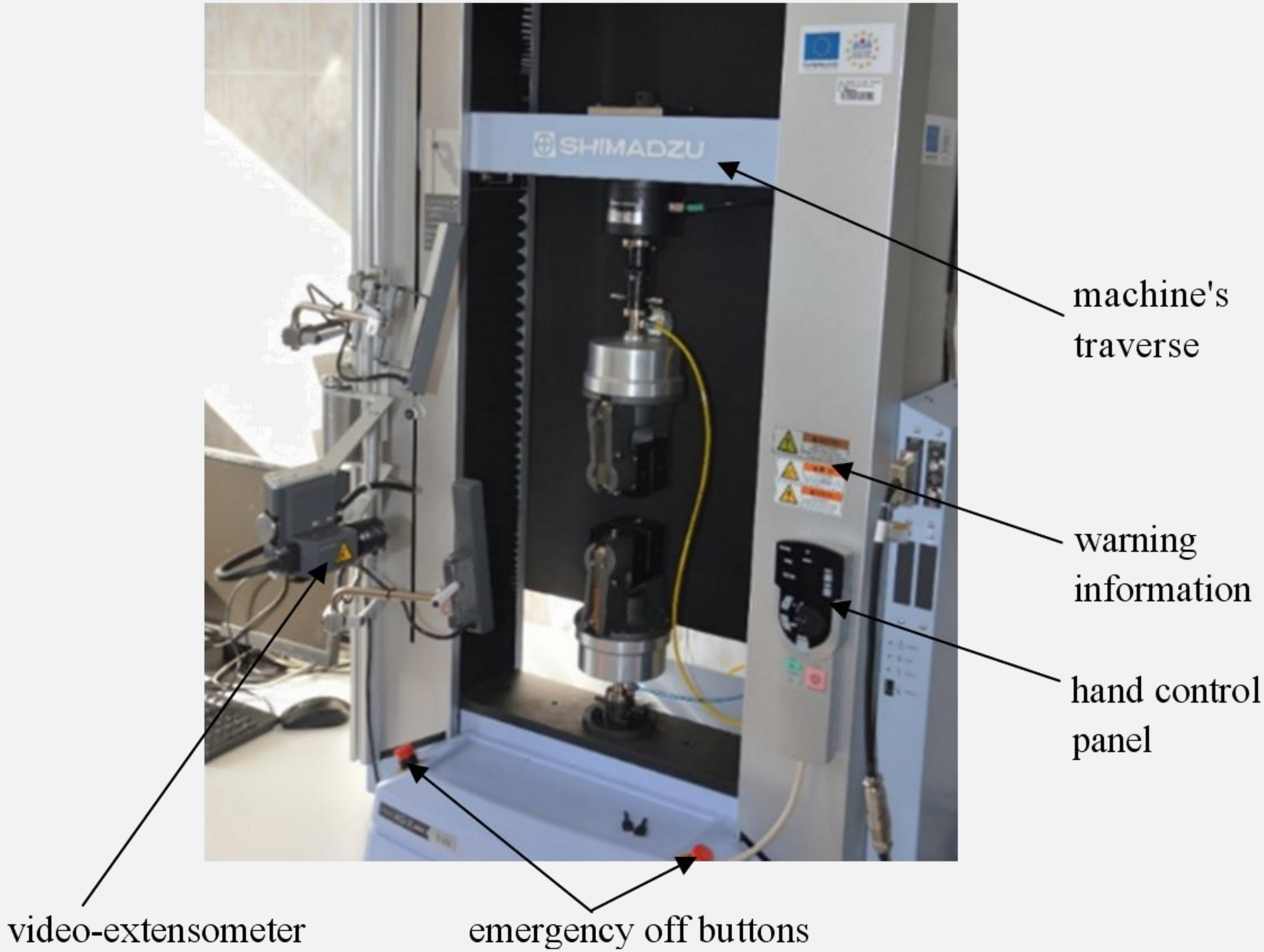
Tire tests are needed for verification analyses between simulations and experimental data. The knowledge of deformation characteristics of tires and tire stiffness values are necessary for computational modeling of tires.

It is necessary to deal with cyclic tensile tests of long-fiber composites which consist of textile reinforcement with a different cord angle as tire casings or conveyor belts.

The Autograph AG-X plus 5kN – Shimadzu Japanese testing machine with a video-extensometer for large strain at tensile tests of composite materials with elastomer and viscoelastic materials with the test Control mode of TrapenziumX version 1.5.1 software is used for the tests of cyclic loading in tensile with cycle loops.

Testing machine: Autograph AG-X plus 5 kN – Shimadzu with a video-extensometer

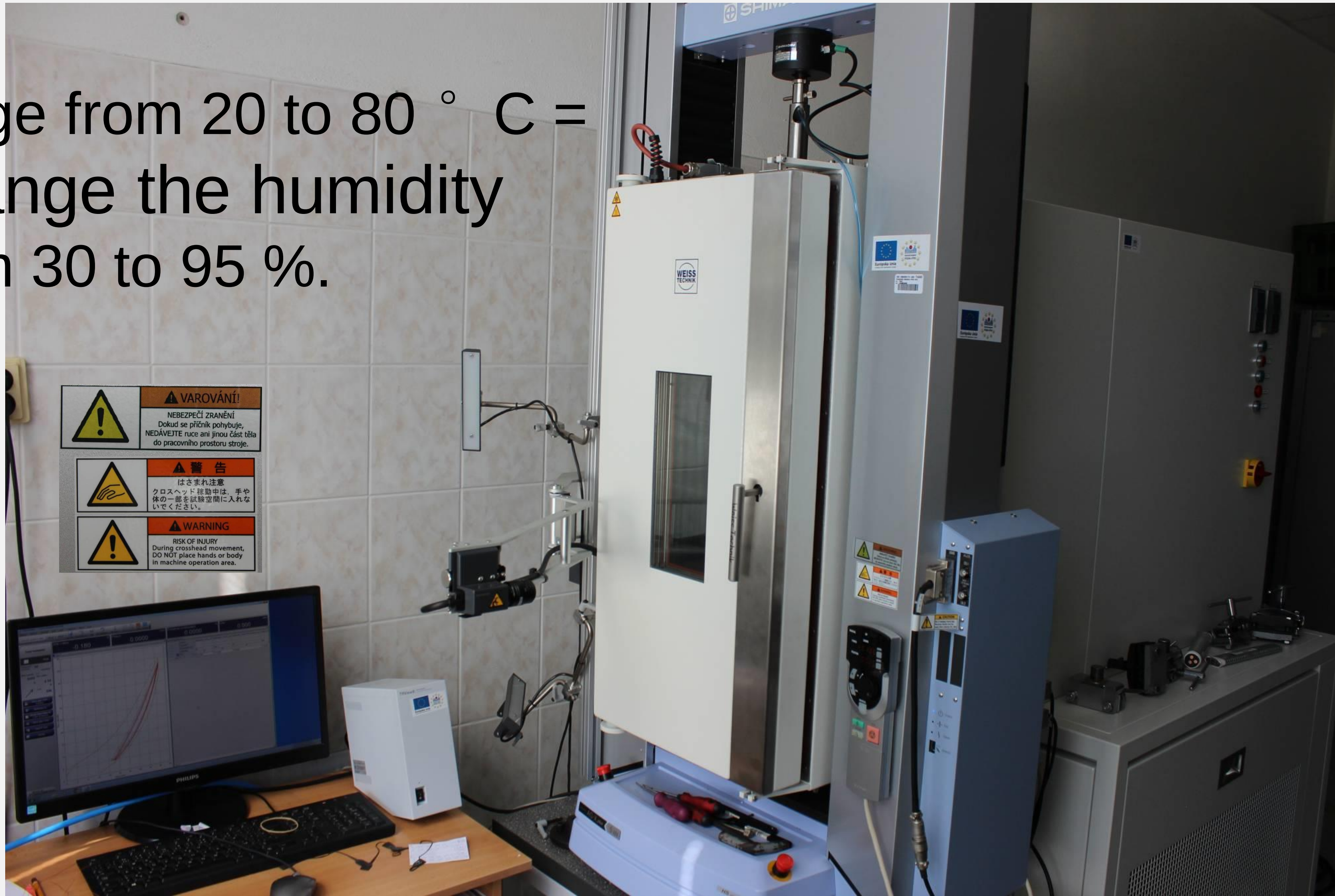
Control mode of TrapenziumX software.



Autograph AG-X plus 5 kN – Shimadzu with a video-extensometer with a hybrid temperature-humidity chamber

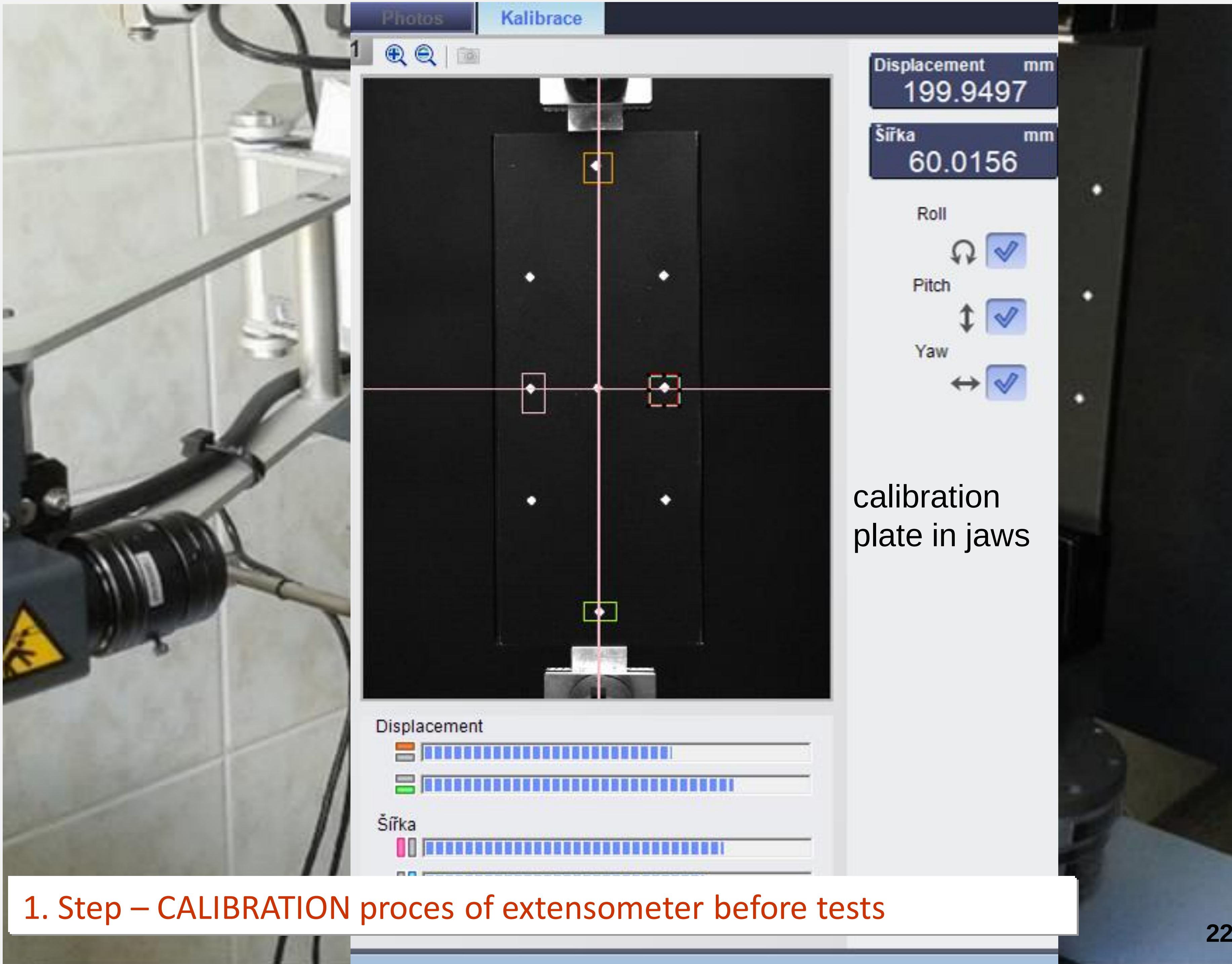
from -60 to 180 ° C

range from 20 to 80 ° C = change the humidity from 30 to 95 %.



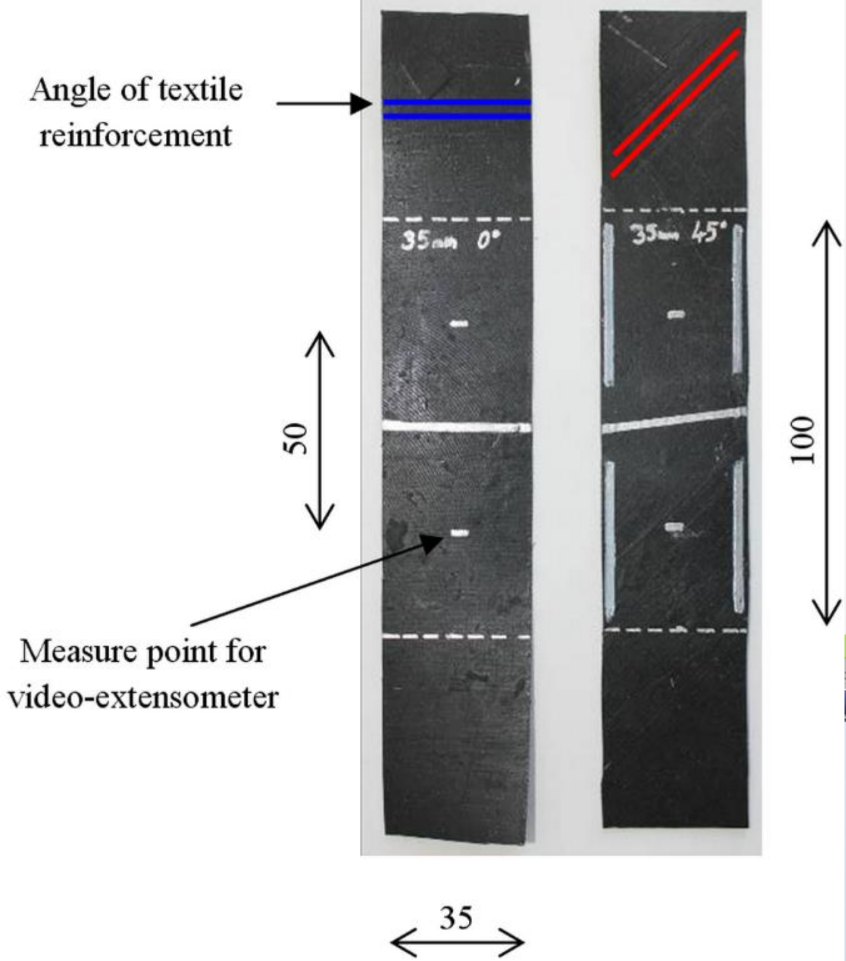
The method for cycle loading tests of composites with a textile fiber and an elastomer matrix has these conditions: the loading speed 250 mm/min for cycles and 50 mm/min for a pre-test by force value 2 N. The geometric parameters of rectangle shape specimens are a length of 195 mm, a width of 35 mm, initial length between clamps of a test machine 100 mm and a thickness of the specimen of 1.05 mm. The initial length between the points for a video-extensometer is 50 mm.

Five cycle loops are applied. Every cycle loop consists of five cycles. Every cycle is defined as loading to a certain percentage of elongation between clamps of a test machine and unloading to a certain percentage of elongation between clamps of a test machine. Before the tests, calibration of the video-extensometer is required.



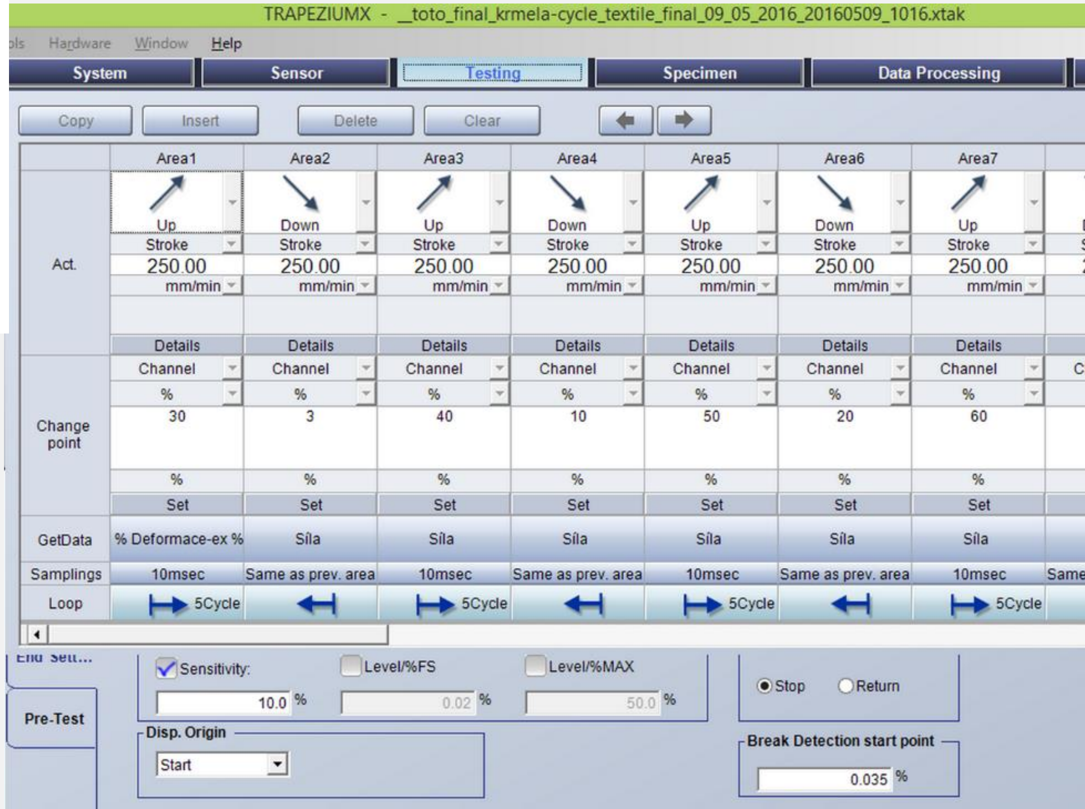
calibration plate in jaws

1. Step – CALIBRATION proces of extensometer before tests



2. Step - Design of SPECIMENS of composite

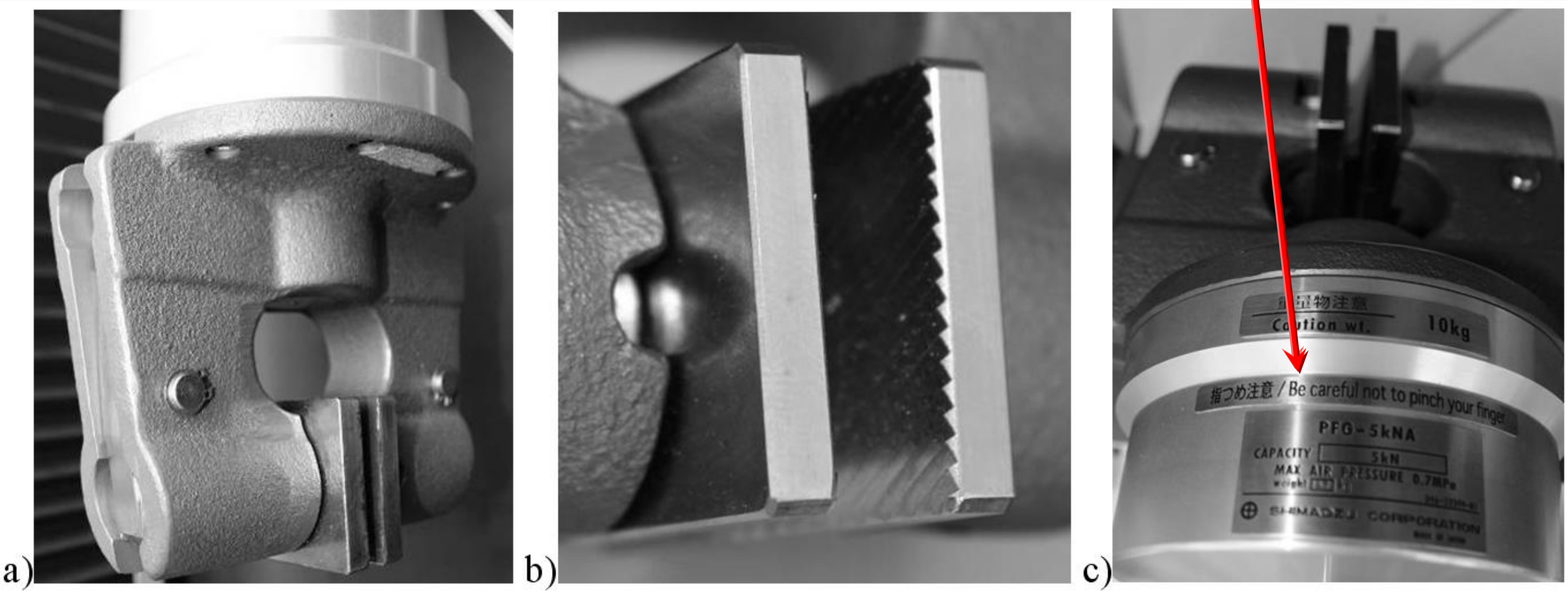
3. Step - Design of METHOD for cyclic loading test



4. Step – MEASUREMENT: operator inserts test samples to compressed-air (pneumatically) jaws.

The operator has to be really careful because there is a risk of <u>finger injuries</u> during closing of the jaws !

On the jaws, the safety information „be careful not to pinch your finger" is stated.



Compressed-air jaws 5kN of testing machine with b) detail of jaws for polymers and composites with rubber matrix and c) warning information „be careful not to pinch your finger" on the jaws

The operator risks of injury from mechanical moving part - the machine's traverse moving during force loading.
Next, operator never ever open specimen jaws that is under load. Any load must be removed from the clamped specimen before opening the specimen holders.

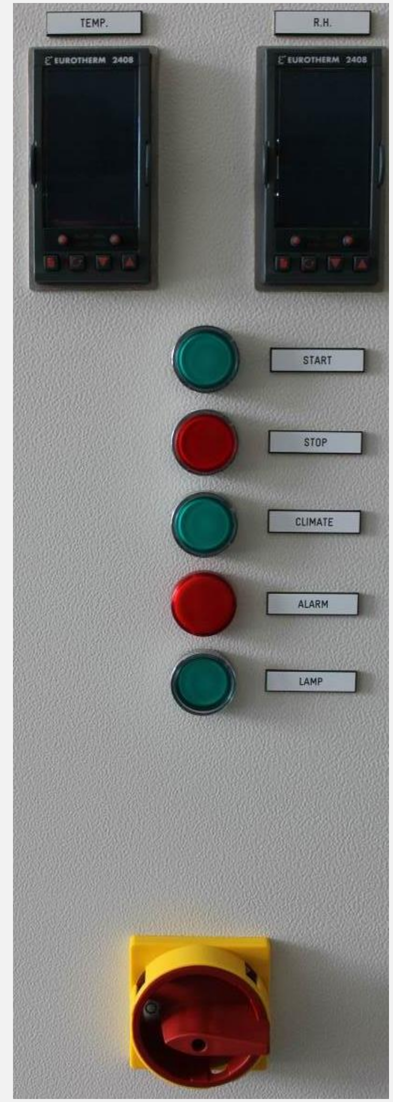
safety information at testing machine

Hybrid chamber:

The operator risks of hand burning (risk of burning or risk of frostbite) during change of samples because high or low temperature is in the during tests and after tests.

The chamber allows to perform the tests from -60 to 180 °C, but it is important to point out that from 20 to 80 °C, it is possible to change the humidity from 30 to 95 %.

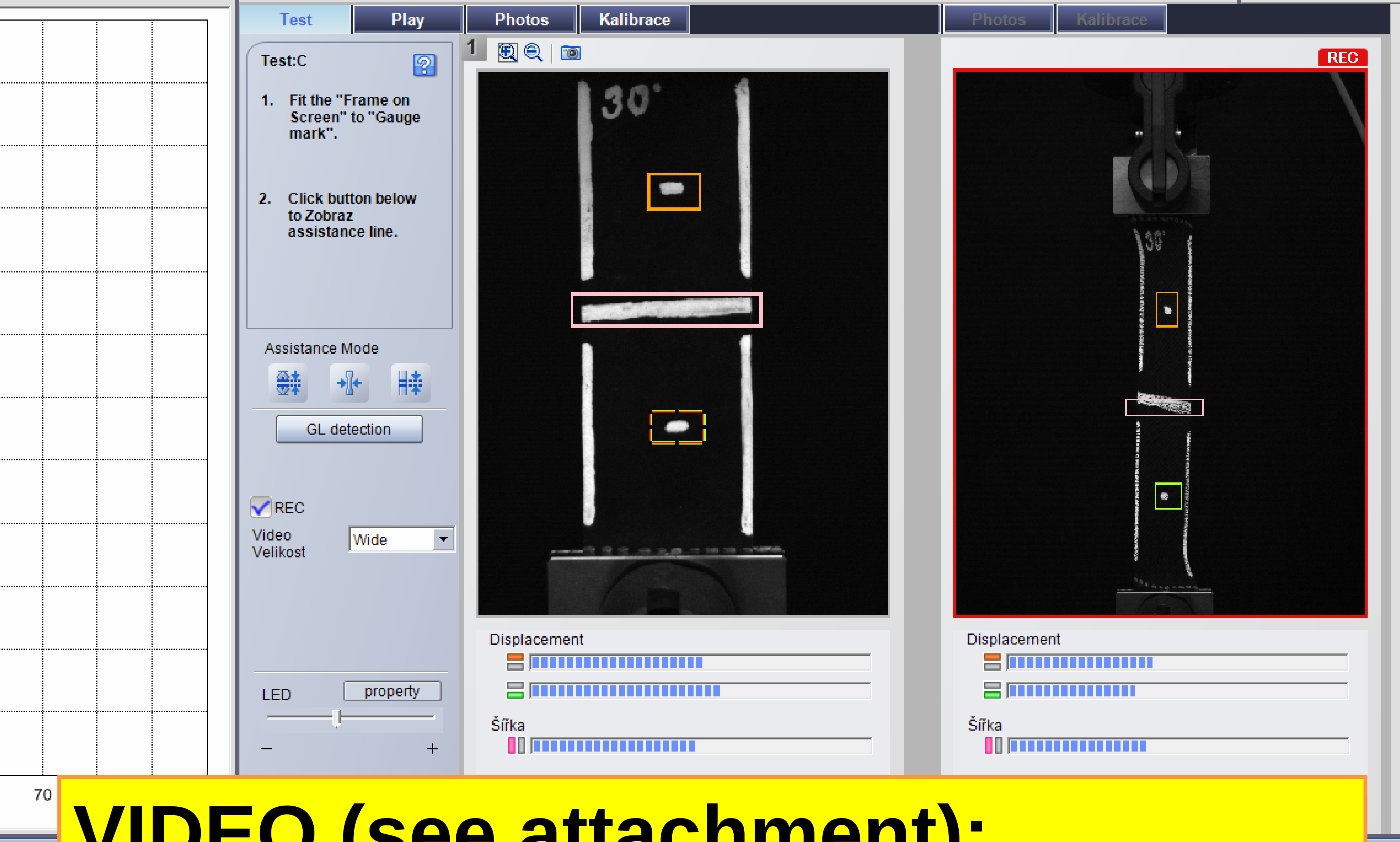
The start/off button is at control panel of chamber.



The hybrid temperature-humidity chamber and detail of control panel – temperature and humidity setting and start/off button on the bottom right

special pneumatically jaw for fibres

there is a risk of finger injuries during closing of jaws



VIDEO (see attachment):

➢ **Composite test** (No. 1)

- Each testing device/machine must be secured with emergency buttons.
- Pictograms must be provided on each device and the operator must be properly trained.
- Nevertheless, the operator must be cautious because there are rotating / moving parts during measurement or prepare of test samples on devices/testing machines such as work on homogenization machine and can be high temperatures used for experiments such as measurement on TGA/DMA analyzer. Therefore, students are not allowed to work on these devices.

THE SAFETY AT WORK IN EXPERIMENTS OF POLYMERS AND COMPOSITES

Summary

The part deals with safety at work during special tests for polymers – polymer fibres and long-fibre composites at on selected laboratory test machines and apparatus. The operators have to be very careful during the test and measure process. We described TGA/DSC analyzer for polymer testing and laboratory line for plasma surface modification and safety at work with this low-temperature plasma reactor. Next, the part described safety at work at laboratory for the production of elastomeric and composites samples which consists from torque rheometer, homogenizing machine, vulcanization hydraulic press and pneumatic hollow die punch. Test samples of elastomers and composites with polymer fibres are the product of this laboratory. These test samples are then tested on universal testing machine with hybrid temperature-humidity chamber.

Key words: safety of work, test, composite, polymer

Introduction

The part deals with safety at work during special tests for polymers – polymer fibres and long-fibre composites at on selected laboratory test machines and apparatus. The safety and warning information on injuries are provided on these devices. High temperatures are applied to the test equipment, and some have moving parts. Therefore, the operators have to be very careful during testing, measurement and production of test samples too.

1. Safety at work at TGA/DSC analyzer to find the crystallinity temperature of polymers

The DSC measurements are carried out using a TGA/DSC 2 HT/1100 STARe System (Mettler Toledo, Schwerzenbach, Switzerland), see Figure 1.

The measurement procedure is: the test samples such as polymer fibres are prepared by cutting to very small stripes of approximately 20 ± 2 mg weight and pressed into aluminum crucibles of volume 70 μl. Subsequently, they are heated from 50 to 250 °C at a heating rate of 10 °C/min in nitrogen atmosphere under the flow rate of 20 ml min^{-1}. Thus, a melting endotherm of sample with melting temperature (T_m) and melting enthalpy (ΔH_m) are obtained. Then the samples are held at 250 °C for 5 min to remove the thermal history of the polymer fibre preparation. The sample are then cooled to temperature 50 °C at a cooling rate of 10 °C/min and the crystallization exotherm with the crystallization temperature (T_c) and crystallization enthalpy (ΔH_c) were obtained.

The melting enthalpy (ΔH_m) are also used for the calculation of degree of crystallinity X_c (%) of the samples according following equation [1]:

$$X_{\mathrm{c}} = \frac{\Delta H_{\mathrm{m}}}{\Delta H_{\mathrm{m}}^{+}} \ \mathrm{x}\, 100 \tag{1}$$

During measurements, there is a hot part on the analyzer with pictogram (see Figure 1, left) because temperature range is from 30 to 600 °C. The operator must be cautious during measurements and when changing the test samples.

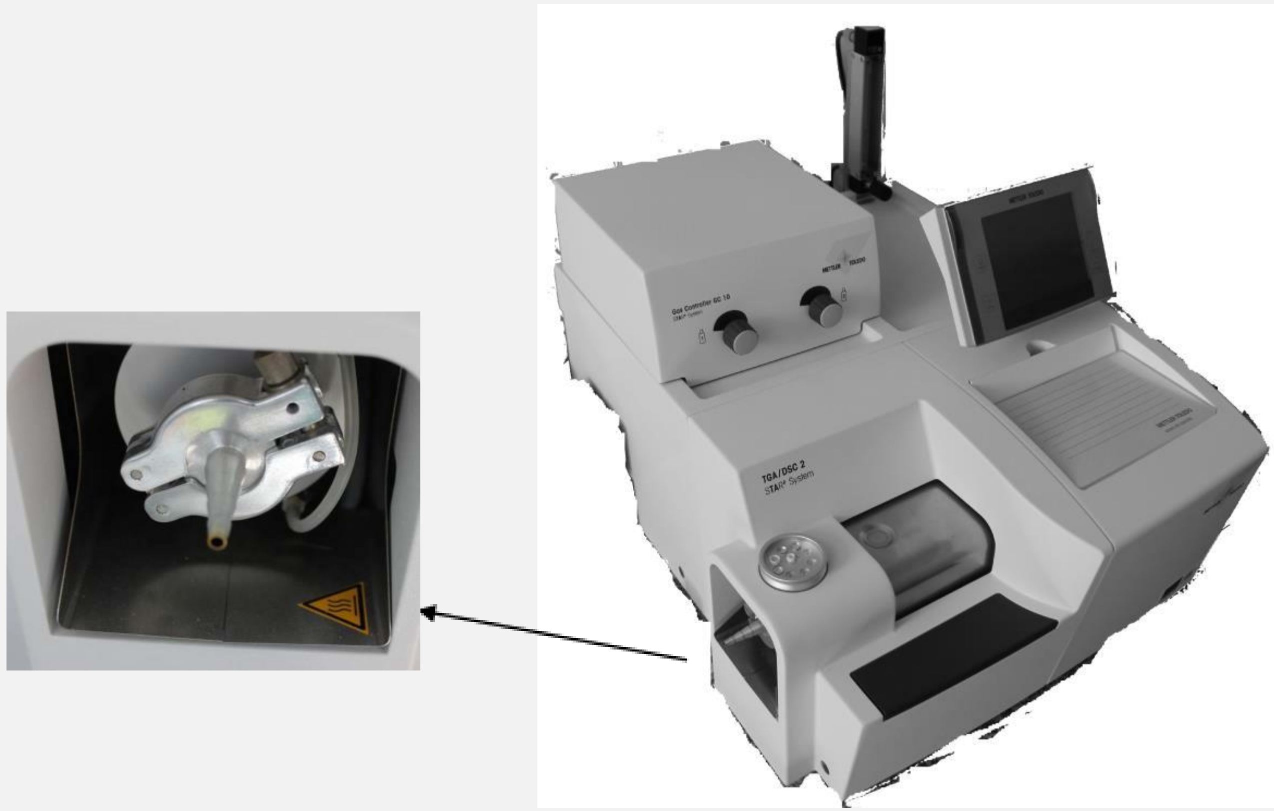


Figure 1. TGA/DSC testing analyzer with detail of hot part (left)

Source: own research.

2. Safety at work at plasma reactor for surface modification of polymers

Plasma reactor KPR 200 (Figure 2) using DCSBD (Diffuse Coplanar Surface Barrier Discharge) plasma systems with flat and curved electrode with active plasma area 200 x 100 mm is used for surface modification of surface of polymers too [2]. A unique feature of the plasma source based on DCSBD is a possibility of generating homogenous plasma under atmospheric pressure with virtually any working gas composition without usage of expensive inert gases. Extremely high power density of plasma up to 100 W/cm^{-3} allows short plasma exposure times and thus high speed processing. This allow plasma reactor KPR 20 produced by Research Institute for Man-Made Fibers (Svit/Slovak Republic).

Plasma can be used for continuous double-sided surface modification of thin flat materials (polymers, textiles, metals, glass) and composites (foils with thickness of 50 μm – 0.5 mm, thin flexible polymeric flat plates with thickness of 0.5–1 mm and thin textile materials as well as cords with diameter of 0.1–0.5 mm). The biggest advantages of using low-temperature plasma in comparison with other “physical” methods of activation of polymer fibre surface are low costs, high speed of the process and efficiency up to the depth of about 10 nm. Plasma action on nanometric level on polymer fibre surface allows to create quite a new class of innovative materials and their use. It is environmentally friendly process because no chemicals are used.

Figure 2. Plasma laboratory equipment

Source: own research.

Contact with the human body and the plasma electrode system is not dangerous, but unless the contact occurs, it is not uncomfortable. During the plasma treatment the ozone is formed, but ozone is exhausted. The devices are always tailor-made for specific customer applications and are necessary to focus on work safety. Our plasma reactor has several drawbacks as unprotected rotating parts of the equipment. There is possibility of electrostatic charges and possibility of improper use of electrical wiring. The on/off (total stop) button is only on the control panel. There is possibility of burning during operation of the device. It has a high sound level.

3. Safety at work at laboratory for the production of elastomer and composite samples

The laboratory consists from:

- torque rheometer for mixing and extruding elastomers,
- homogenization machine,
- vulcanization hydraulic press,
- pneumatic hollow die punch.

The torque rheometer Brabender Plastograph® EC plus (Figure 3) is used for simulation of elastomer processing and manufacturing procedures under the laboratory conditions – heating, blending, mixing, reactive mixing, kneading. There is a very hot chamber (working temperature can be up to 500 °C) with rotation parts with revs up to 150 min^{-1}. During machine running the operator must be very careful. Risk of burns.

Figure 3. Torque rheometer with detail of hot chamber with pictograms

Source: own research.

As next step, there is homogenization process of elastomer. The homogenizing machine from company Vogt at Figure 4 is used. The temperature is changed during homogenization process (maximum temperature is 150 °C). There are very hot rotating parts – two heated rollers. In addition, hair and clothing of operator may be pulled in, see pictograms on machine.

As next step, there is vulcanization process on vulcanization hydraulics press LabEcon 600, see Figure 5. The product is vulcanizing plate [3] with defined thickness. The press is fully automatic and the operator is protected by a safety cover. The maximum temperature is 300 °C but standard temperature for vulcanization process of elastomer is from 150 to 180 °C. In addition, emergency buttons are located.

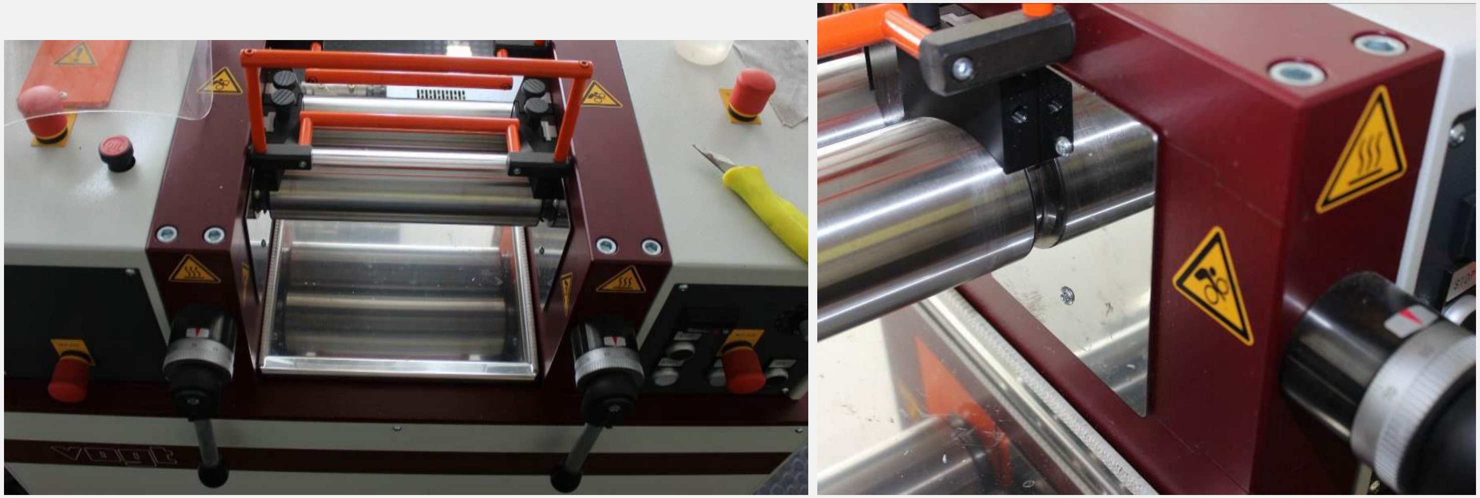


Figure 4. Homogenization machine with detail of rotating heated rollers and hot parts (right)

Source: own research.

Figure 5. Full automatically vulcanization hydraulics press

Source: own research.

After press, the test samples with standard shapes according to ISO 37 [4] (see example at Figure 6 left) from the vulcanizing plate are made on pneumatic hollow die punch Inston, see Figure 6 right. There is a risk of injury to the fingers, so the control buttons for run of device are located on both sides of the device and must be pressed by the operator with both hands at the same time. Thus, the moving part cannot come into contact with the operator's fingers.

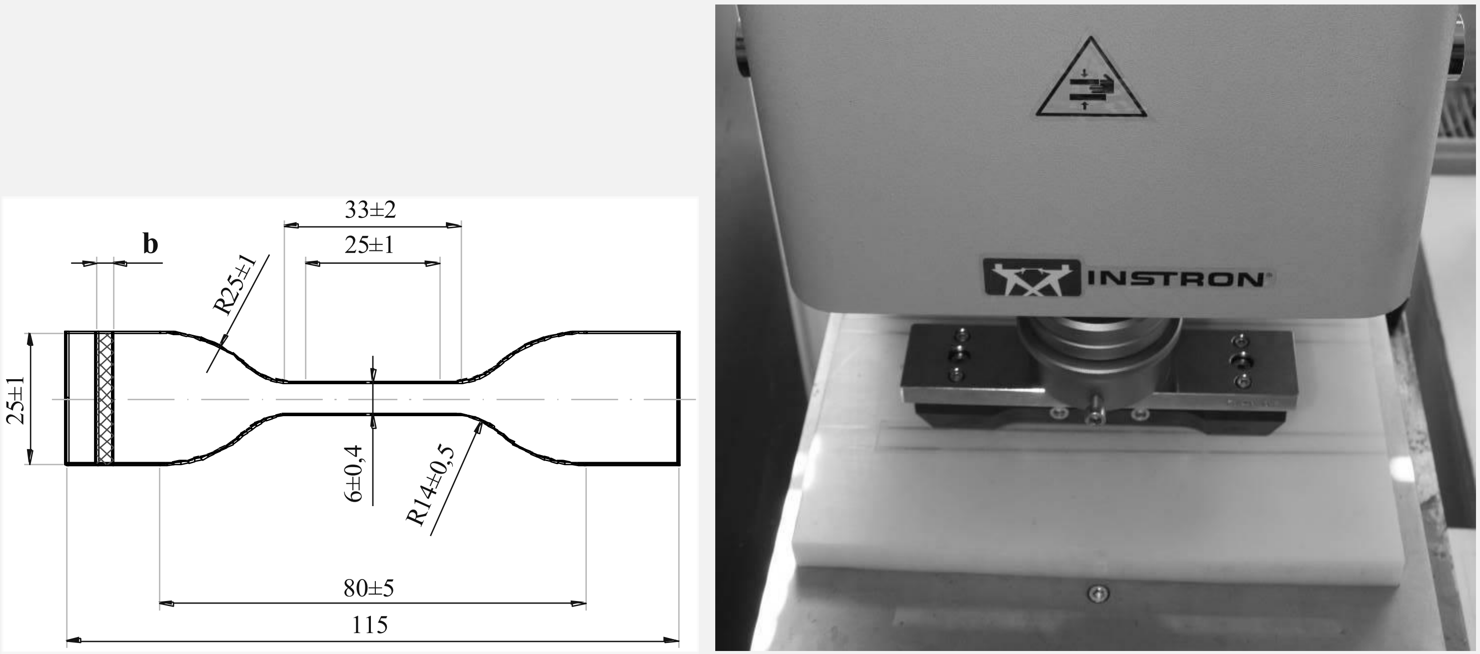


Figure 6. Pneumatic device for the production of test samples with shape of samples (left)

Source: own research.

For prepare polymers from granulates, the torque rheometer Brabender Plastograph® EC plus with measuring extruder with six temperature zones is used, Figure 7. The extruder is very hot during mixture and extrude process.

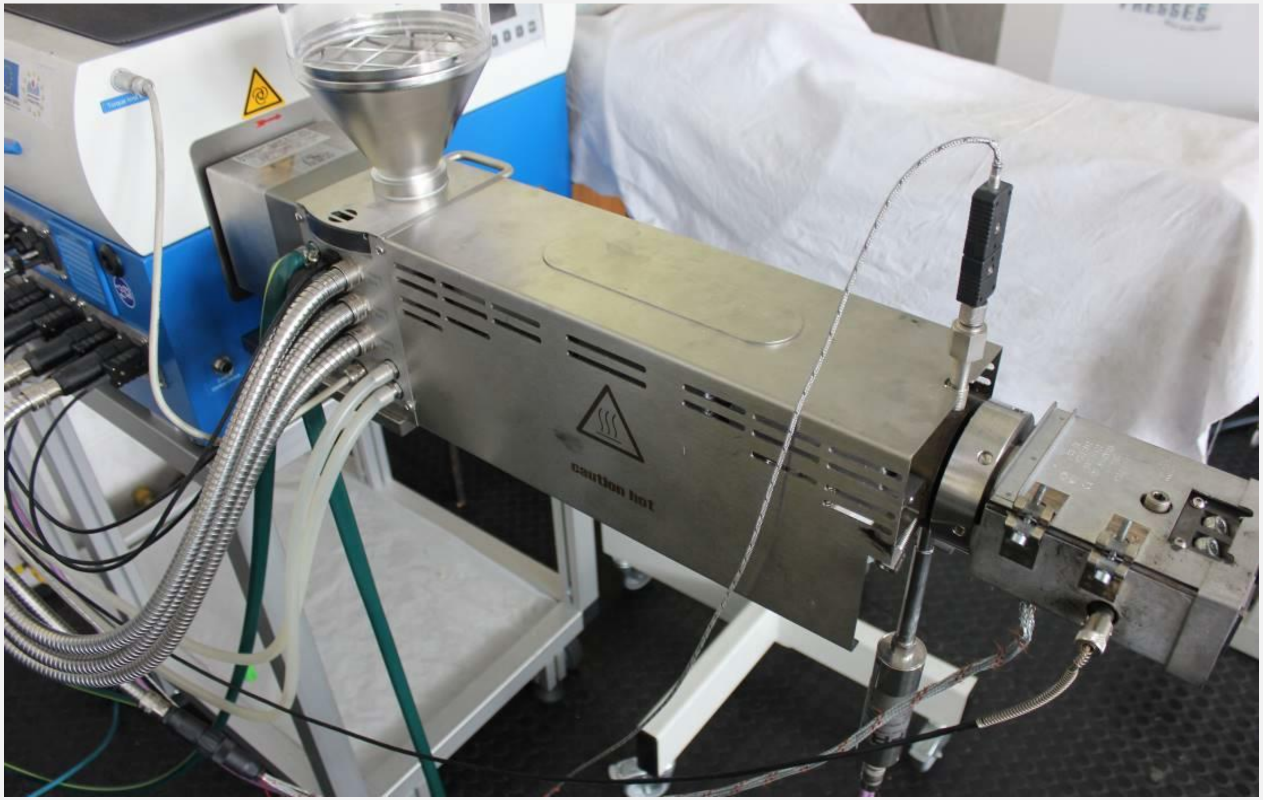


Figure 7. The measuring extruder of torque rheometer for production of polymers

Source: own research.

4. Safety at work during tensile tests of polymer fibres and composite samples

The Autograph AG-X plus 5kN – Shimadzu Japanese testing machine with hybrid temperature-humidity chamber (Figure 8) and special jaws (see Figure 8 c) is used for the tests of polymer fibres [5]. The chamber allows to perform the tests from -60 to 180 °C, but it is important to point out that from 20 to 80 °C, it is possible to change the humidity from 30 to 95 %.

The operator has to be really careful because there is a risk of finger injuries during closing of the compressed-air (pneumatically) jaws. Also, the operator risks of hand burning (risk of burning or risk of frostbite) during change of samples because high or low temperature is in the during tests and after tests. The start/off button as emergency button is at control panel of chamber and emergency buttons is at testing machine.

a)

b)

c)

Figure 8. Universal testing machine (a) with hybrid chamber (b) and detail of special jaw for fibres (c)

Source: own research.

5. Conclusion

Each testing device/machine must be secured with emergency buttons. Pictograms must be provided on each device and the operator must be properly trained.

Nevertheless, the operator must be cautious because there are rotating / moving parts during measurement or prepare of test samples on devices/testing machines such as work on homogenization machine and can be high temperatures used for experiments such as measurement on TGA/DMA analyzer. Therefore, students are not allowed to work on these devices.

Acknowledgement: The contribution was supported by the Cultural and Educational Grant Agency of the Slovak Republic (KEGA), project No. **KEGA 002TnUAD-4/2019**.

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THE SAFETY DURING 3D PRINTING OF TECHNICAL OBJECTS ON 3D PRINTER

3D PRINTER

FOR CREATION OF SAMPLES AND PROTOTYPE OF TECHNICAL OBJECTS

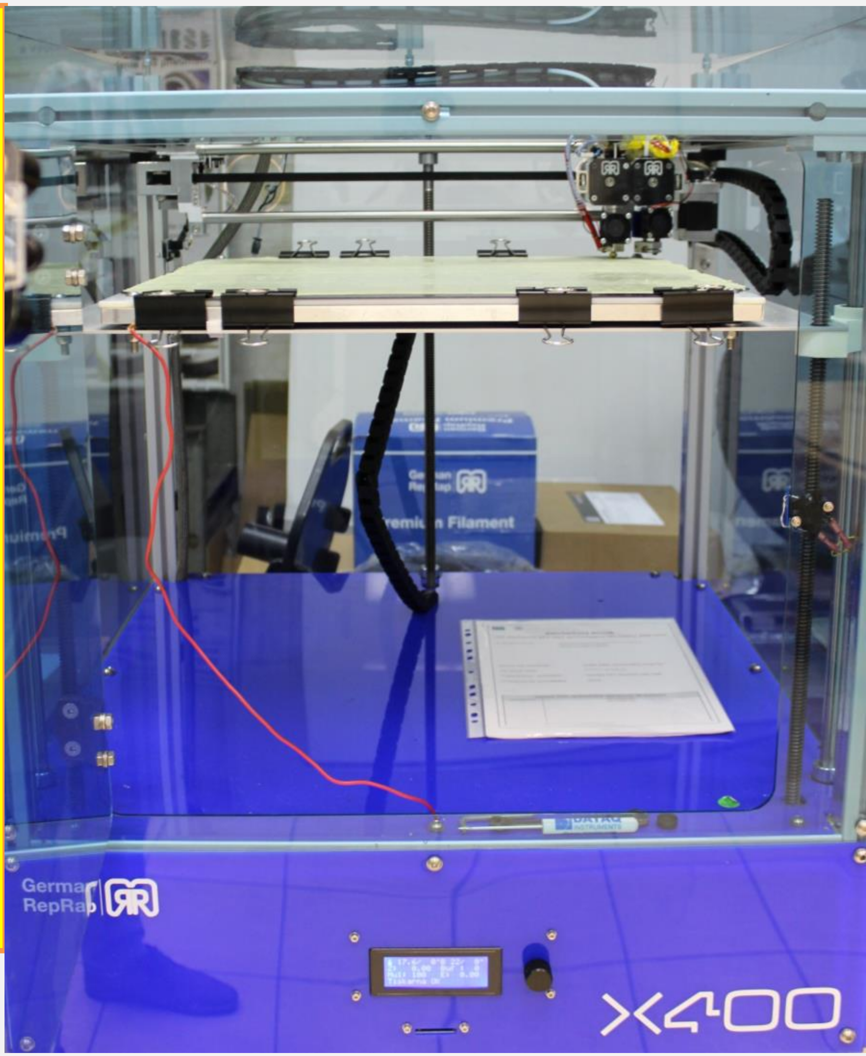
3D printer with two nozzles based on FFF (Fused Filament Fabrication) process is used for 3D printing of technical objects and rapid prototyping.

3D PRINTER
Model: X400 PRO V3

German RepRap

Technology: <u>Fused Deposition Modeling (FDM) method</u>
(sometimes the abbreviation FFF is used)

This X400 printer was the first printer in Slovakia and Czech republic (at April 2016)!

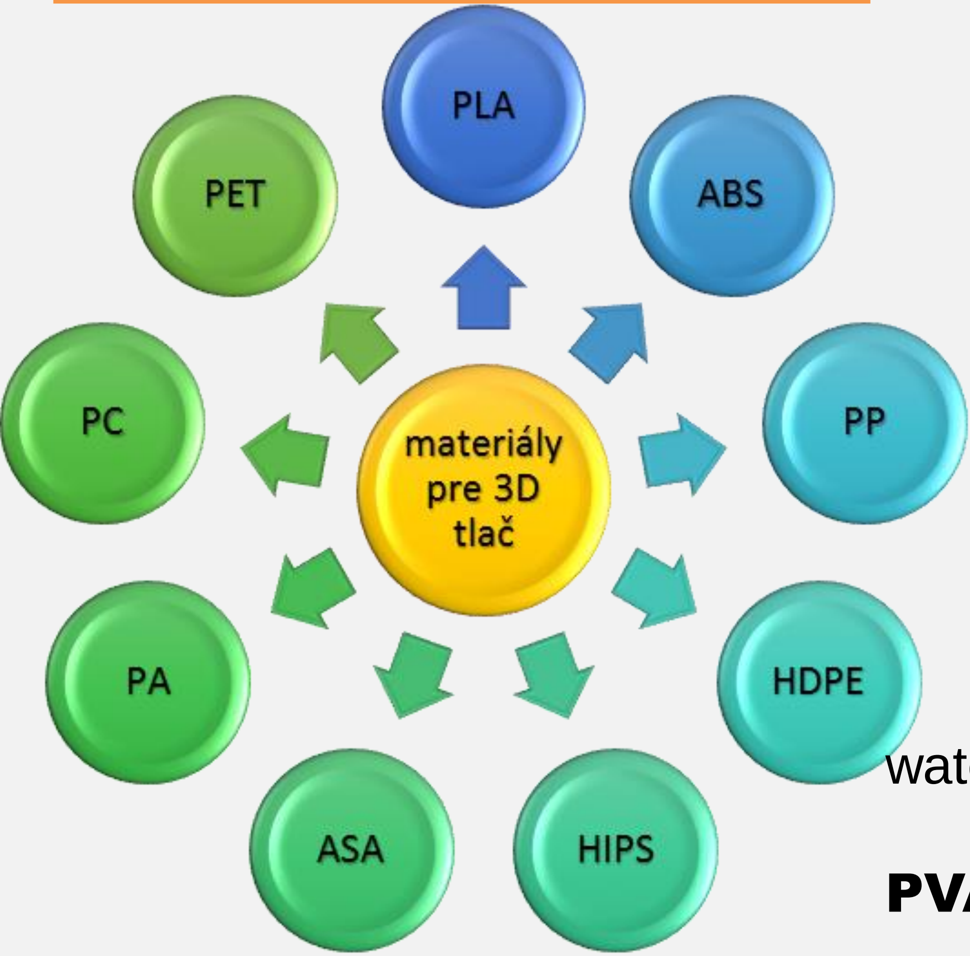


German RepRap GmbH

What is FFF technology ?

1) 3D design of the **stl format** (e.g. 3D object, which created by SolidWorks or Rhinoceros or other)
2) **imported into „slic" program**. Selected type of device, model fill method, layer thickness, other setting.
3) The output from the program is special file **G-code format** (coordinate axis) for 3D printer.
4) In the nozzle, the building **material is heated** to the desired temperature and the molten material is passed through the nozzle opening. The temperature is **higher than the melting temperature**.

Materials for FFF



ASA – acrylonitrile styrene acrylate,
PA – polyamide,
PC – polycarbonate,
PET – polyethylene terephthalate,
PLA – polylactic acid,
ABS – acrylonitrile butadiene styrene,
PP – polypropylene,
HDPE – high density polyethylene,
HIPS – high-impact polystyrene

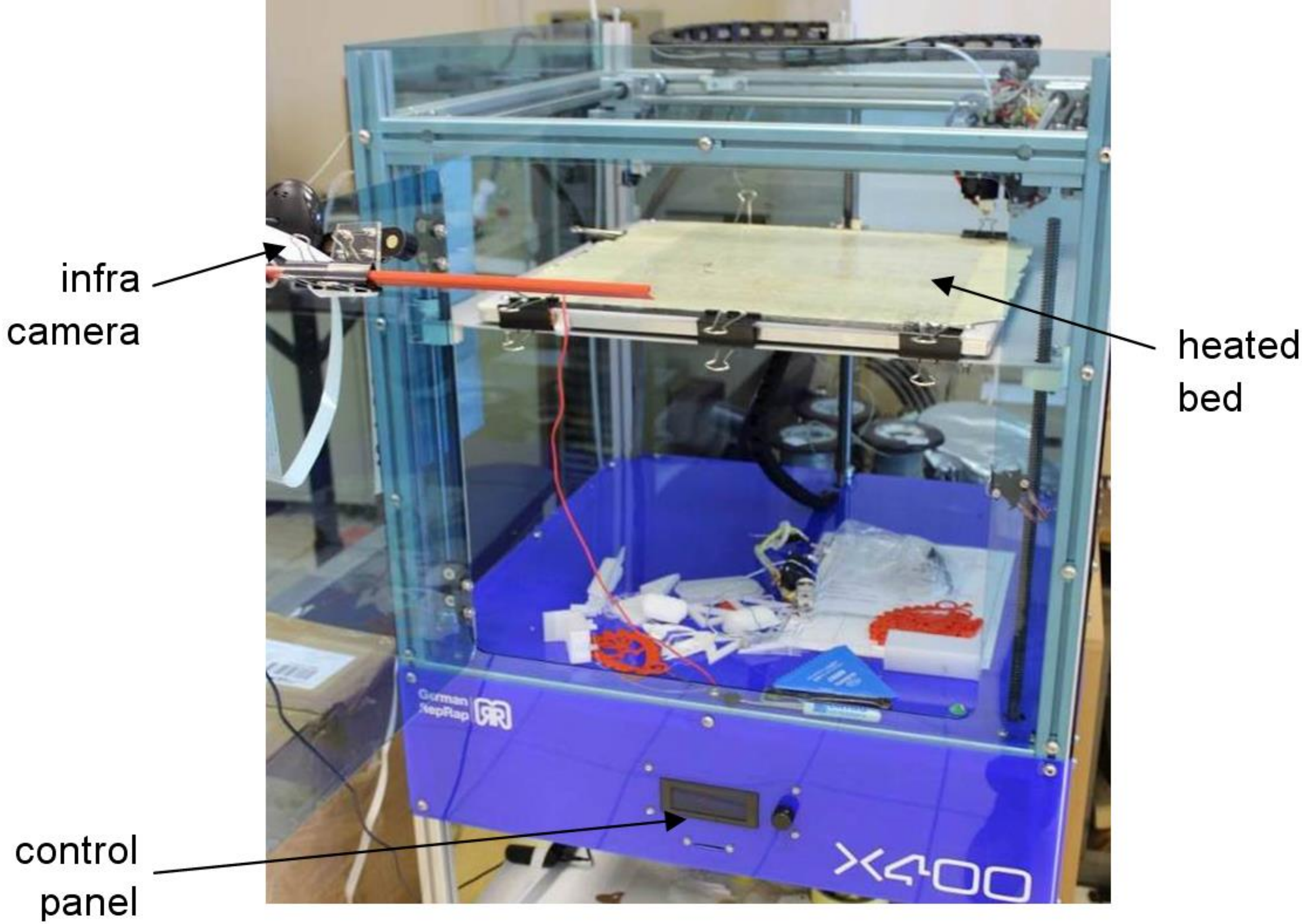
water soluble **support material** such as

PVA (polyvinyl alcohol) for PLA or

HIPS fro ABS

The choice of material depends on the use of the printed object. Each material has different mechanical properties.

SPOOL:
PLA (Polylactic Acid) (diameter 1.75 mm, 2.1 kg)
Nozzle temperature 210-212 °C
Head bed temperature 60-70 °C



GERMAN REPRAP X400 3D printer with infra camera for on-line night watching printing process

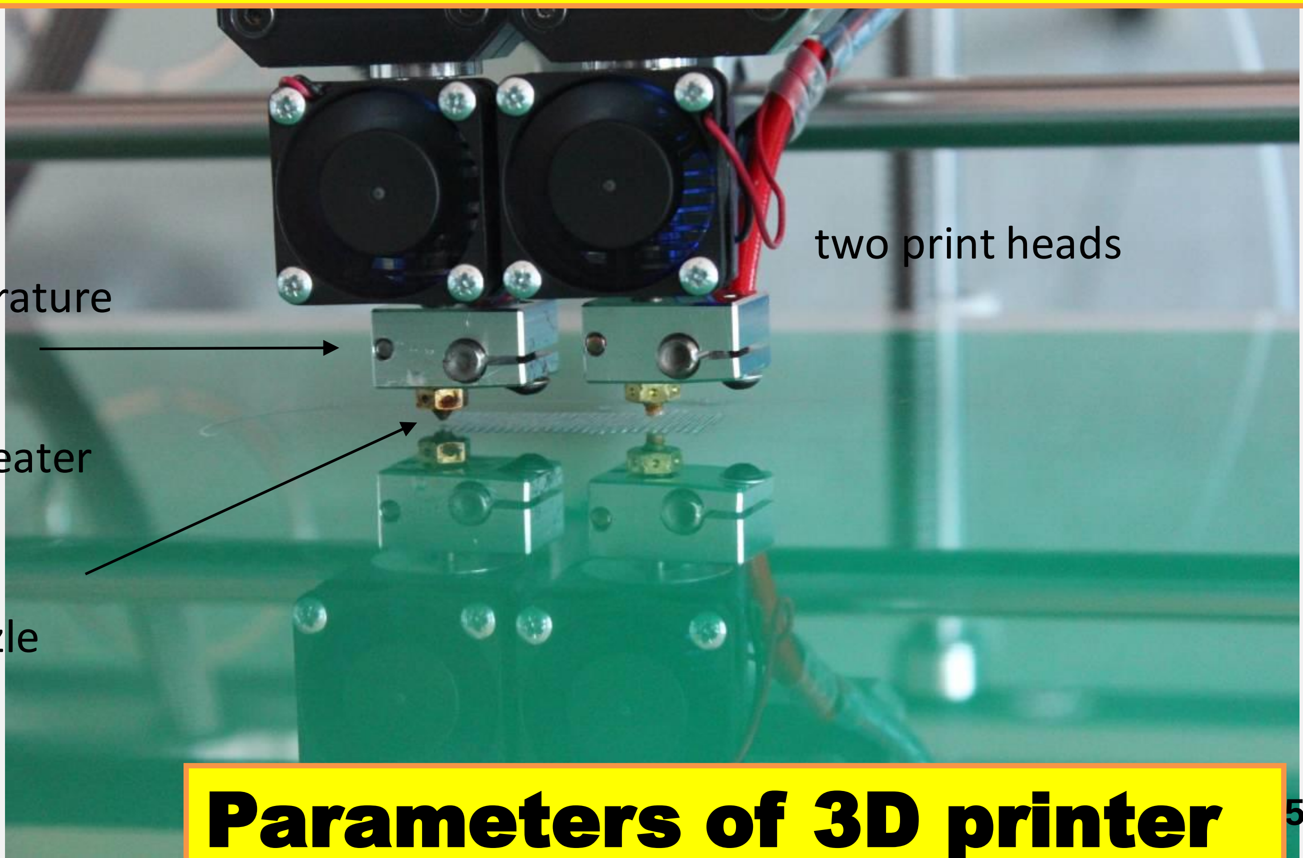
The GERMAN REPRAP X400 version Pro V3 3D printer is used for printing of technical objects and rapid prototyping. The print coils with a filament different diameter range 1.75 – 3.0 mm are used for 3D printing. The build platform is 390 x 400 x 326 mm. The printer has DD3 dual extruders. The extruders can be heated to 290 °C. It is possible printing with different materials, not only standard ABS and PLA and printing in two colors or with water soluble support material such as PVA (polyvinyl alcohol) for PLA or HIPS for ABS parts. If PLA is used for printing, then nozzle temperature is 210 °C and heated bed temperature is 65 °C according to the data by producer of specific PLA. The 3D printer can be operated via an LCD display and turning knob with an SD-card reader.

Big space of build platform **390 x 400 x 326 mm !**

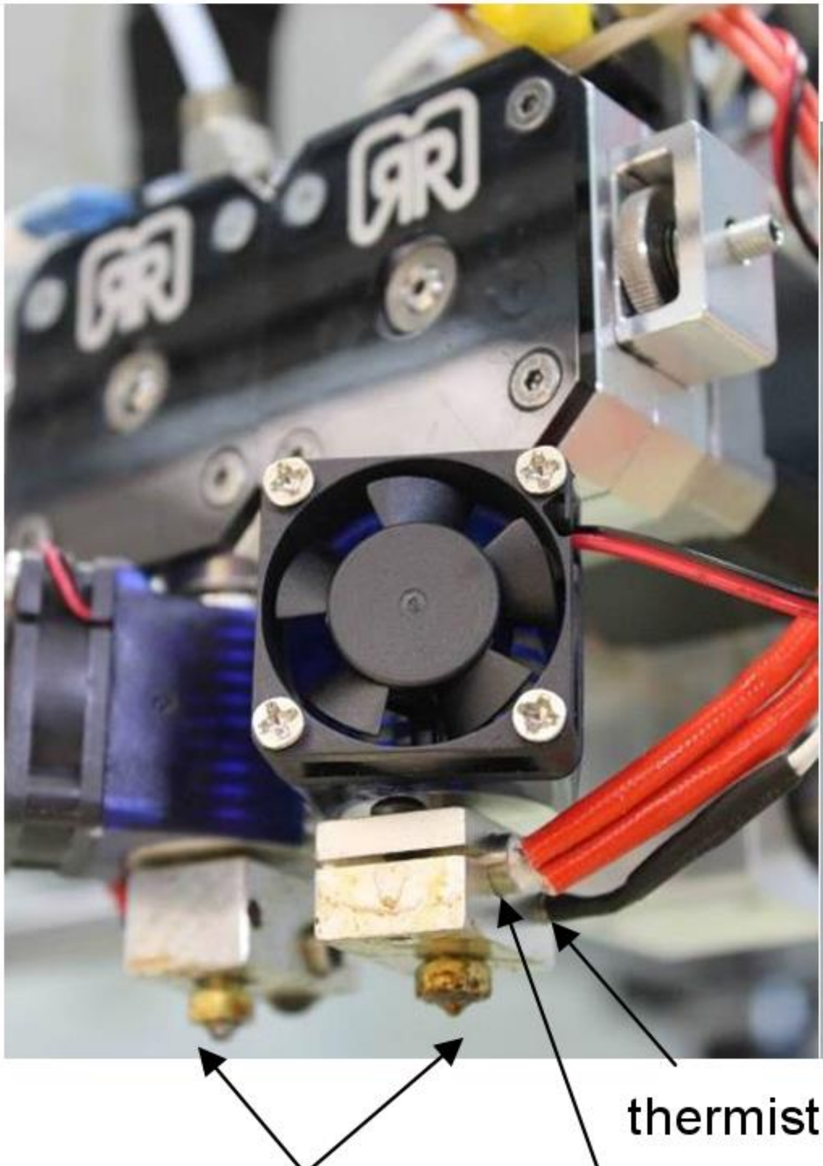
Materials: ABS, PLA, Nylon, TPU93, Carbon20, Laywood, Laybrick, Soft-PLA, aj. (**<u>max. temperature 290 °C</u>**) – **different materials !**

DD3 Dual extruders (2 nozzles) **Heated bed** max. **120 °C.**
Filament with a diameter of 1.75 mm.

Nozzles:
0.80 mm
0.60 mm
0.45 mm
<u>0.40 mm</u>
0.25 mm

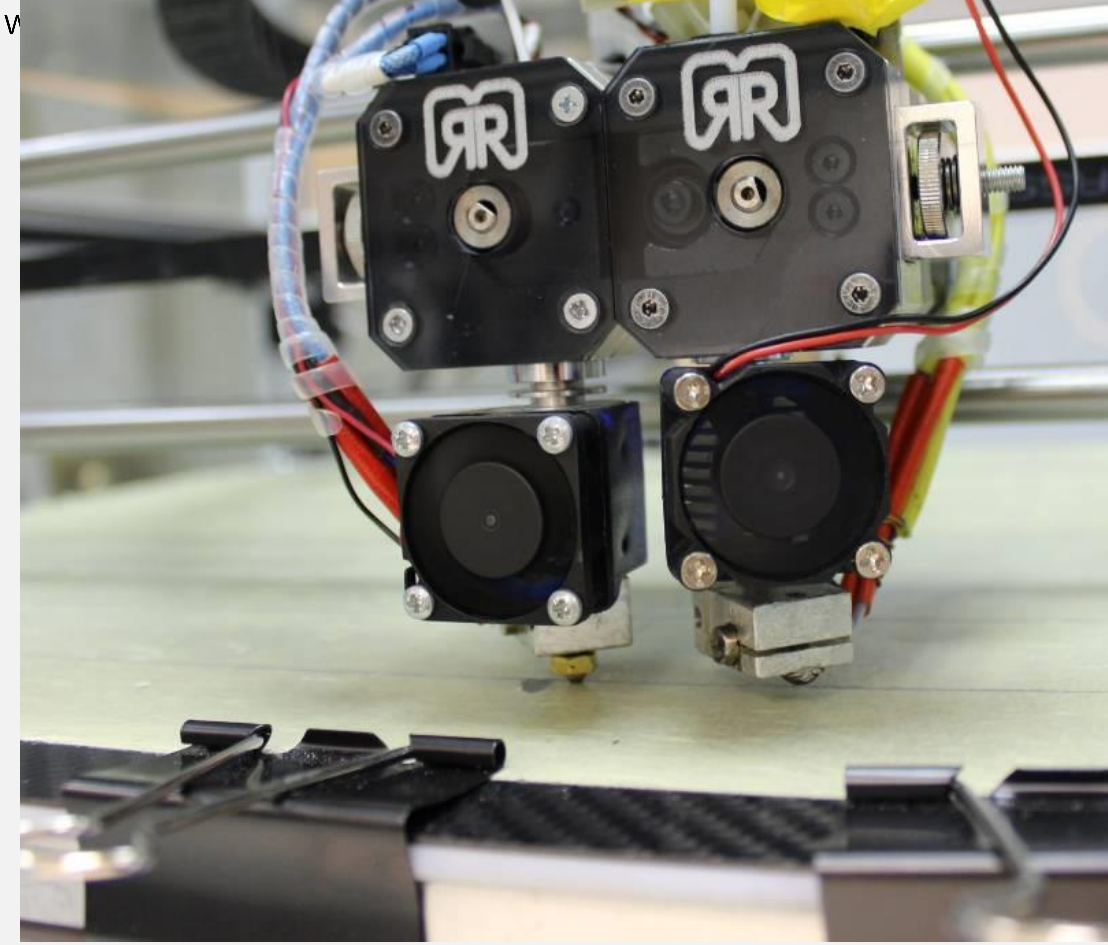


Parameters of 3D printer

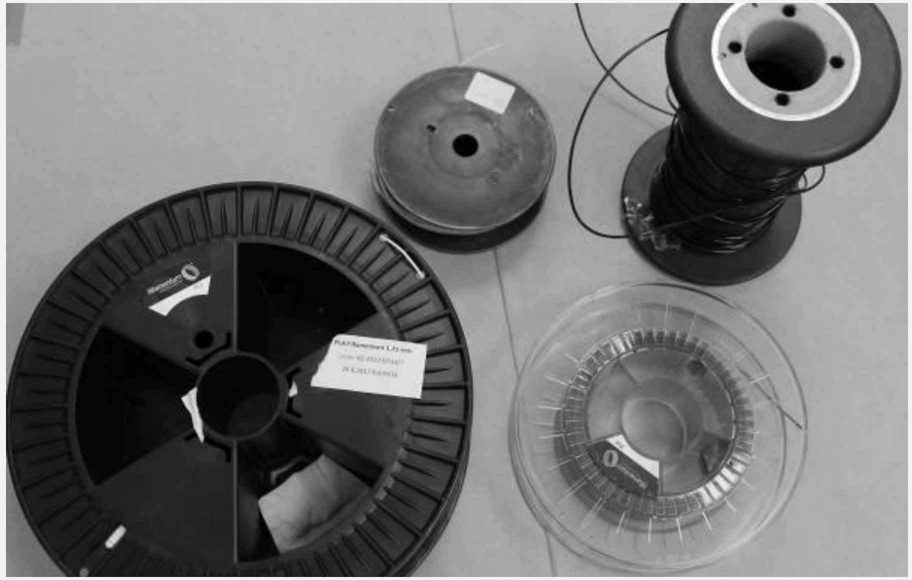

thermistor
heating
two extruder units with
stepper motors and fans


The extruders can be heated to
290 °C
There is a risk of burns
during the exchange of the filament.


E1: 23.2/ 0°C→ 0%
E2:266.5/265°C→ 0%
B: 26.4/ 0°C→ 0%




Painting tape
Carbon pad
Glass table
Heated bed



The print coils with different diameter of coil and different filament diameter and material (down - commercial coils and above - special diameter coils for research of new materials)

Nozzle and heated bed temperatures for selected materials for 3D printing

Material	Nozzle temperature [°C]	Heated bed temeperature [°C]
ABS	245	115
PLA	190–210	65
Flexifill 98A	200–220	70
Timberfill	195	65
polypropylene	245–265	100–110

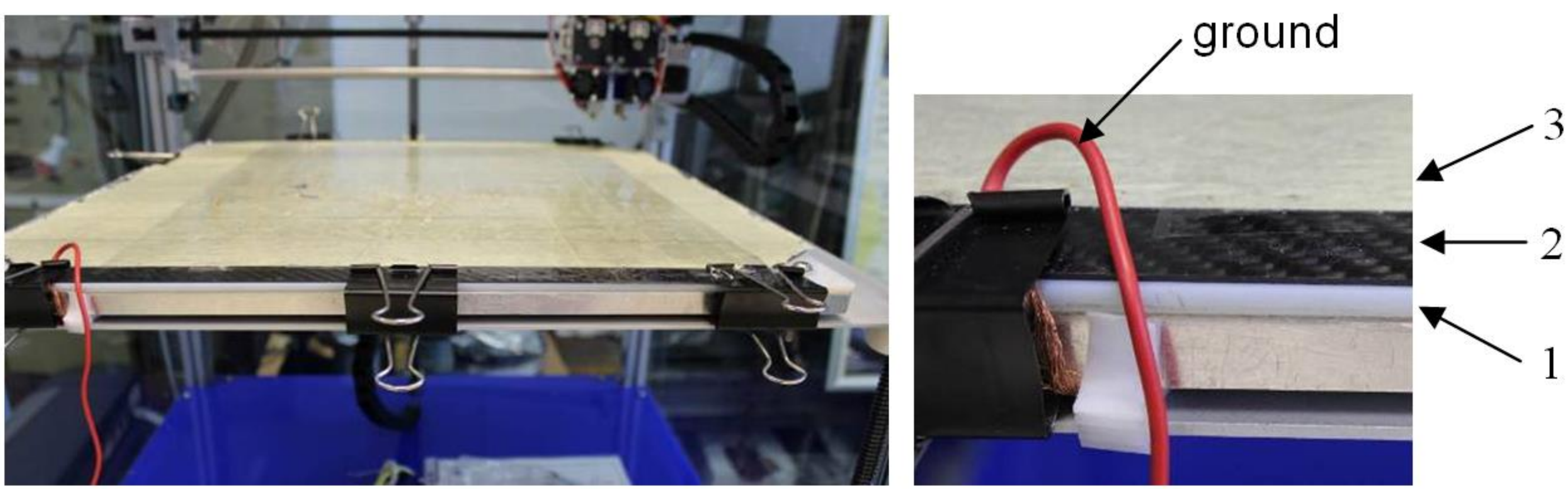
Source: own research.

Exchangeable nozzles with diameters of 0.25; 0.40; 0.45; 0.60 and 0.80 mm are used. The nozzle with diameter 0.40 mm is most used. It is possible printing with two filament diameters, the first nozzle is used for standard 1.75 mm and the second nozzle is used for filament diameter range 1.75 – 3.0 mm for research of new materials.

Maximum temperature of heated bed is 120 °C =

risk of burns.

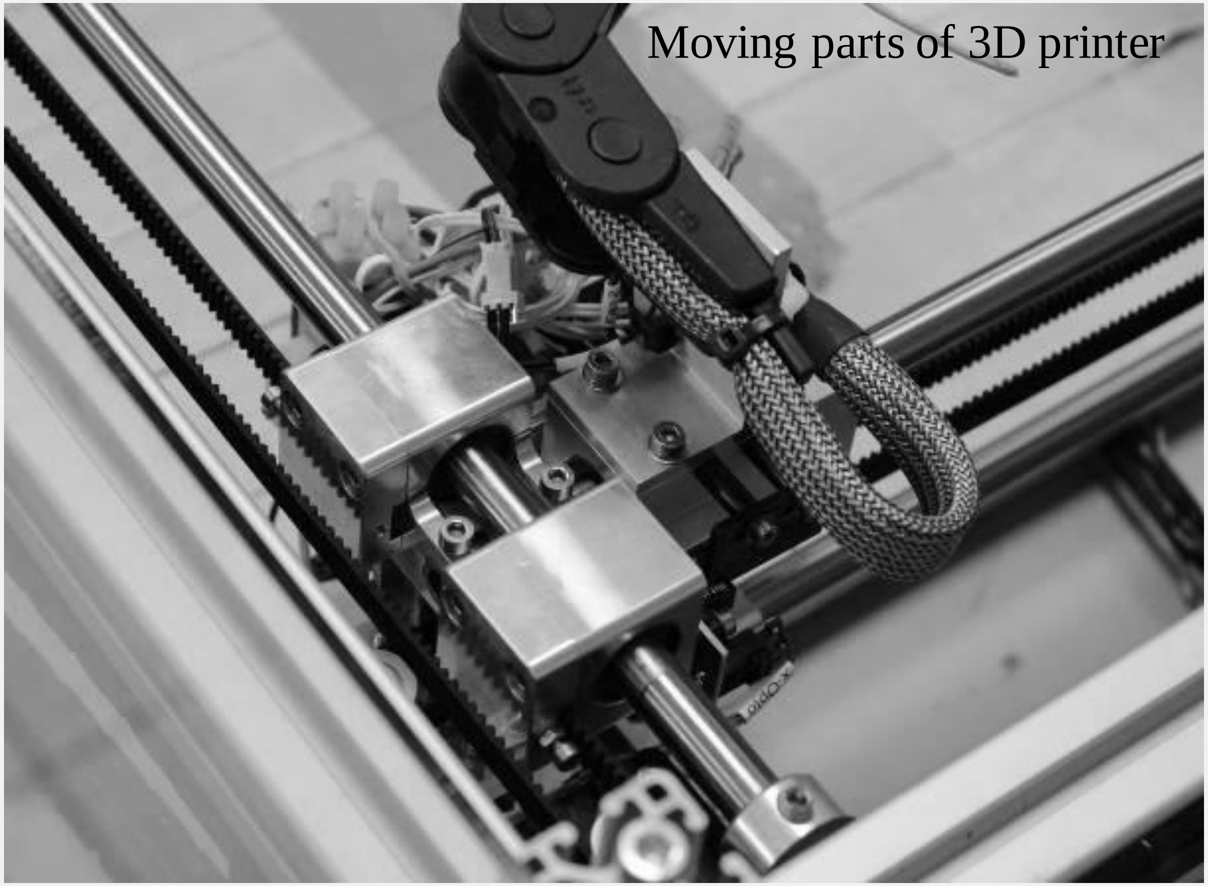
The specific problem = **static electricity** (static buildup) at the heated bed during and after printing.



Heated bed with solution of static electricity, down – composition of heated bed – 1) glass, 2) plate carbon, 3) overlay layer - adhesive paper masking tape or transparent sticky tape

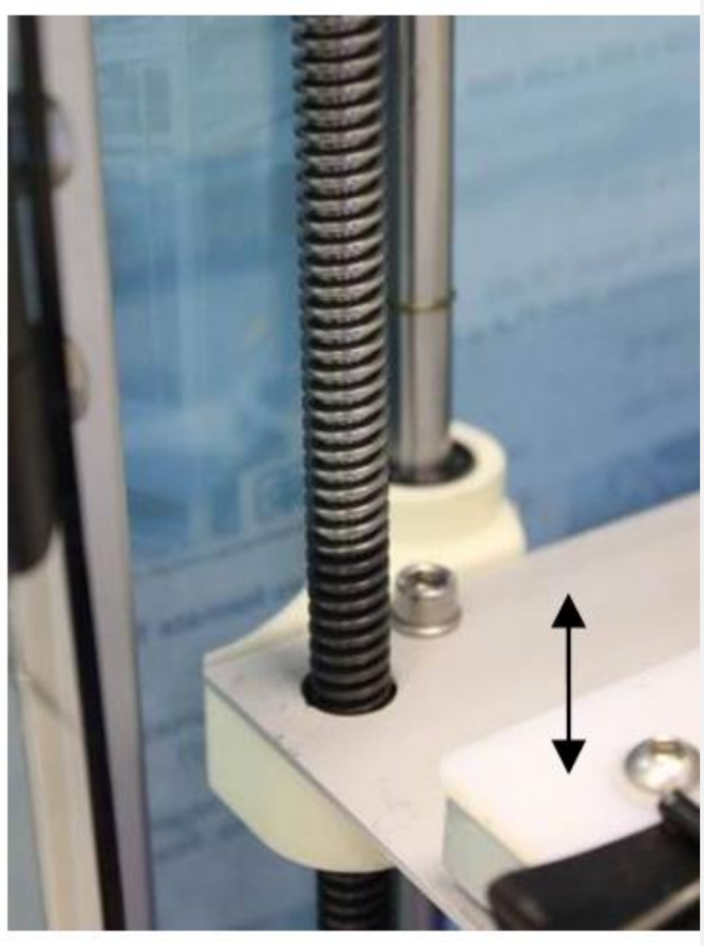
This problem was solved by ground wire.

Similarly, heated bed temperature approx. 110 °C (e.g. for ABS material) may be used. Ensure increased safety during 3D printing. There is a risk of injury by moving parts, on which extruders are of 3D printer. On the Figure you can see sliding mechanism for movement of extruders in x a y axes (move left and right, forward and backward).



Moving parts of 3D printer

During printing, the heated bed moves down (axis z) with the rotating lead screws using. The door of cover 3D during print job can be open. Therefore, long hair or loose clothing could get caught up in rotating lead screws. The operator has to be very careful during the printing process.



PROCEDURE: Geometric model - file format STL

⇓

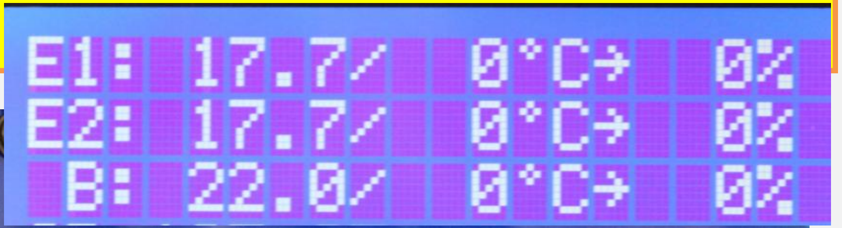
program Repetier Host (open source)
/ Simplify3D (comercionally)

⇓

Slicer ⇒ G-code (**print time, lenght, consumption, price**)

⇓

Possibility: A) Code GCO on SD card and manually operating by LCD

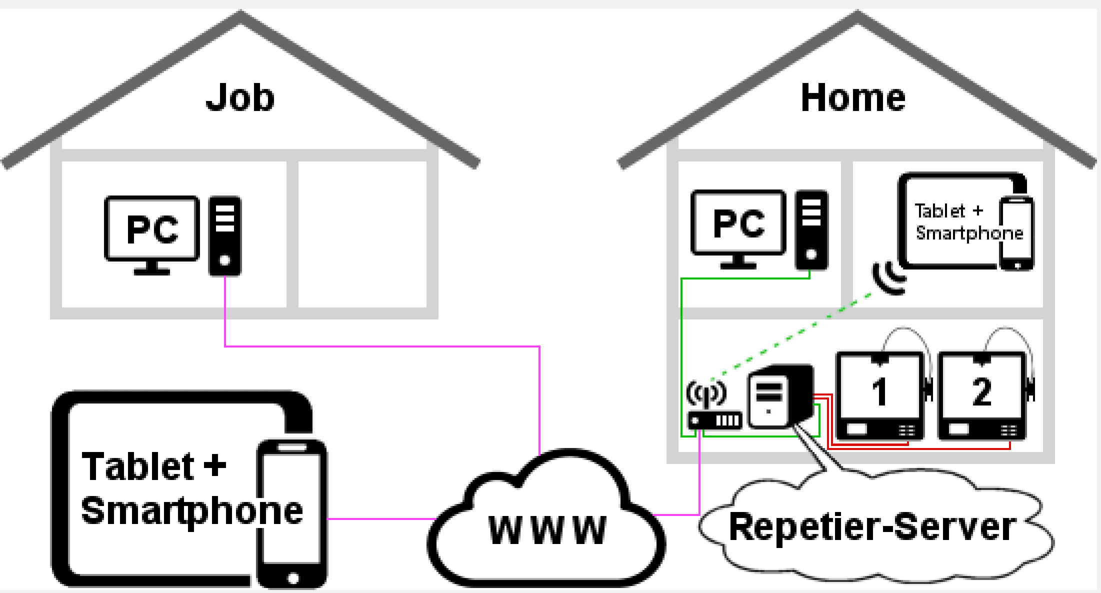


⇓

B) by <u>notebook and direct line from programs</u> Repetier Host or Simplify3D

⇓

C) by <u>notebook by internet</u> (Ethernet/WLAN) and used Repetier Server (observation from long-distance - „from home“) by special 3D print box = RASPBERRY Pi



Cura

Meshmixer

Repetier Host

Simplify3D

Programs for 3D print (all include = slicing, control direct line by notebook by USB cable)

Kisslicer

Slic3r

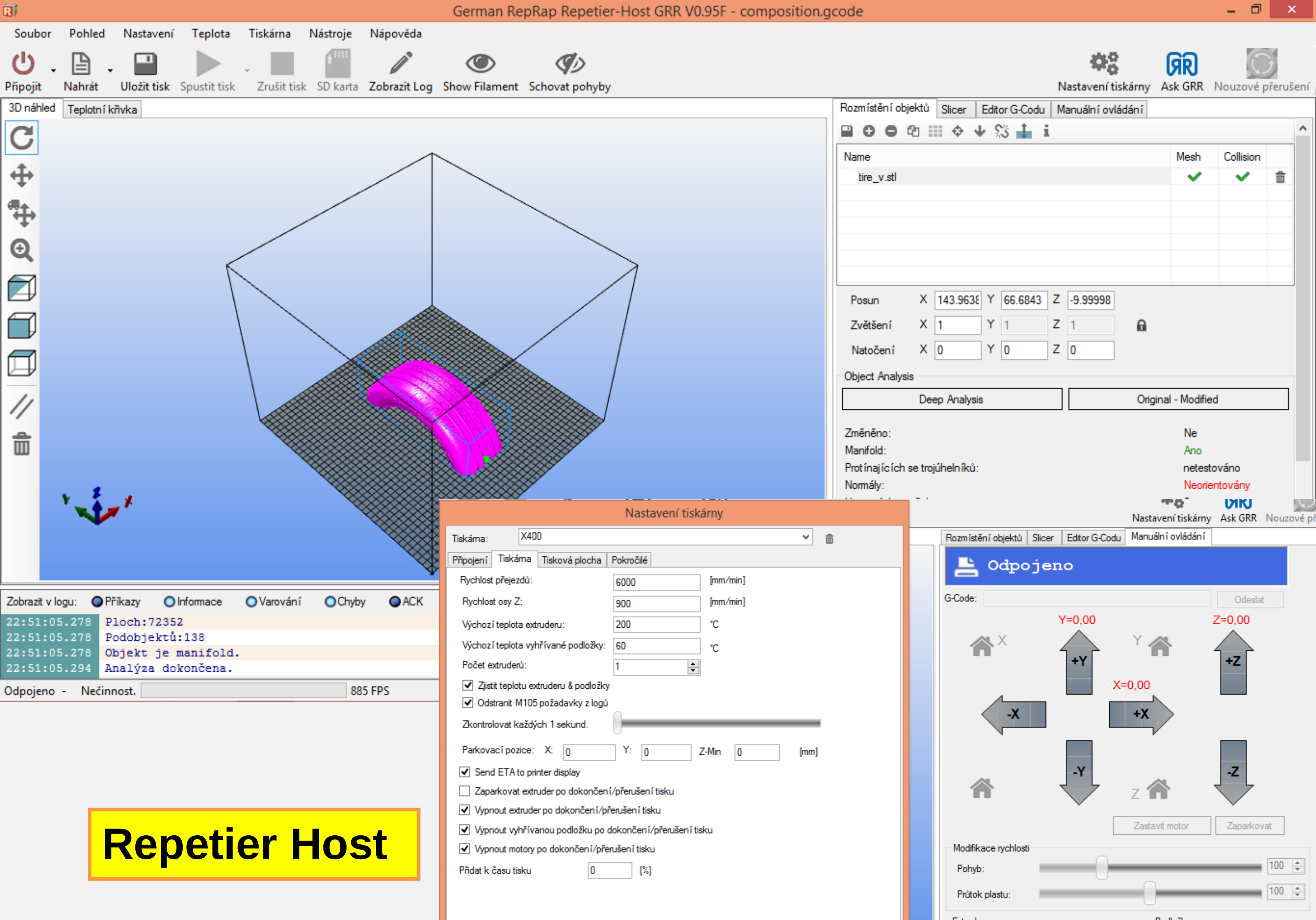
Programs for slicing only

Octoprint

Astroprint

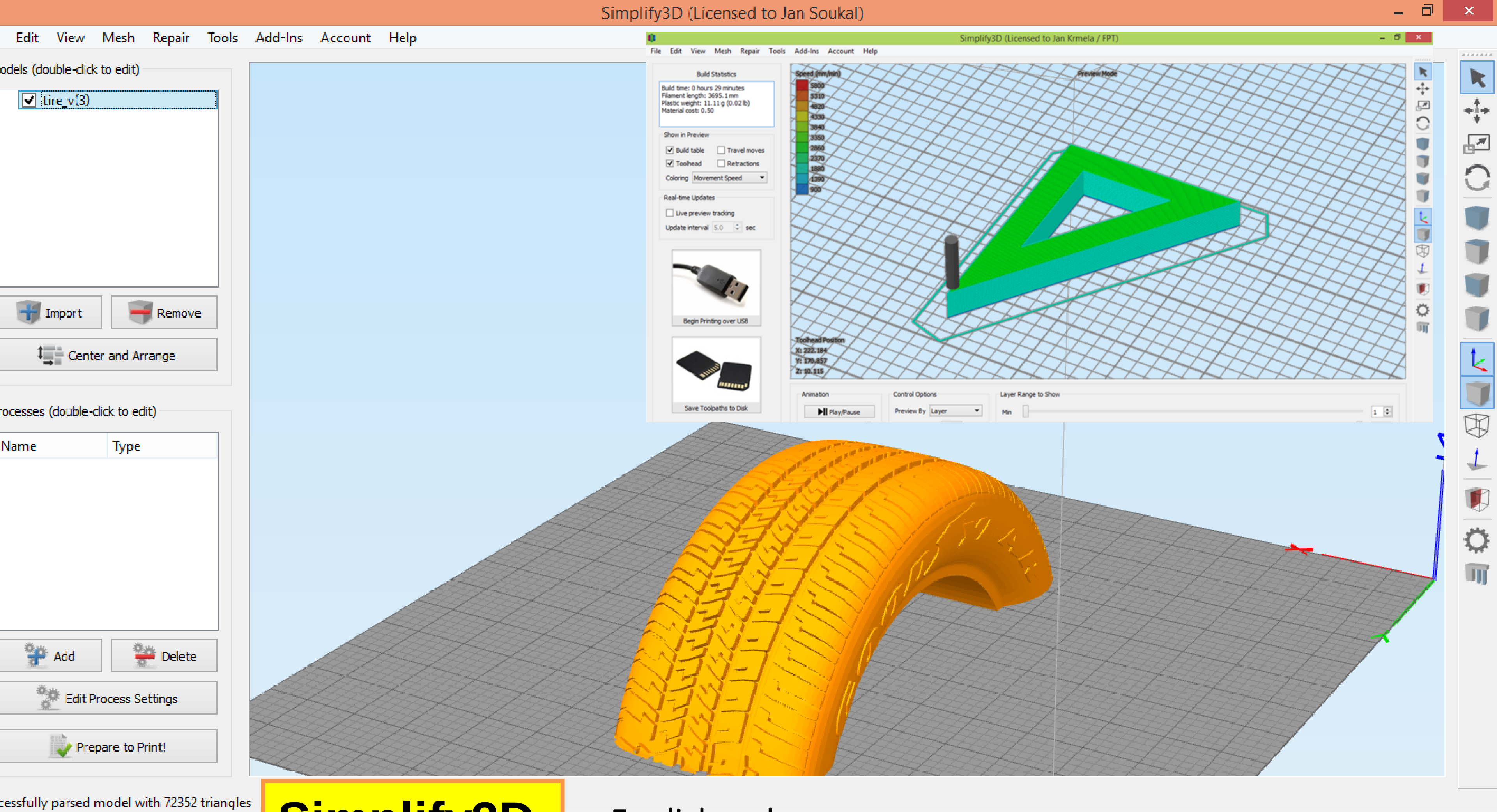
Repetier Server

Programs for from long-distance („from home“) by special 3D print box RASPBERRY Pi



Repetier Host

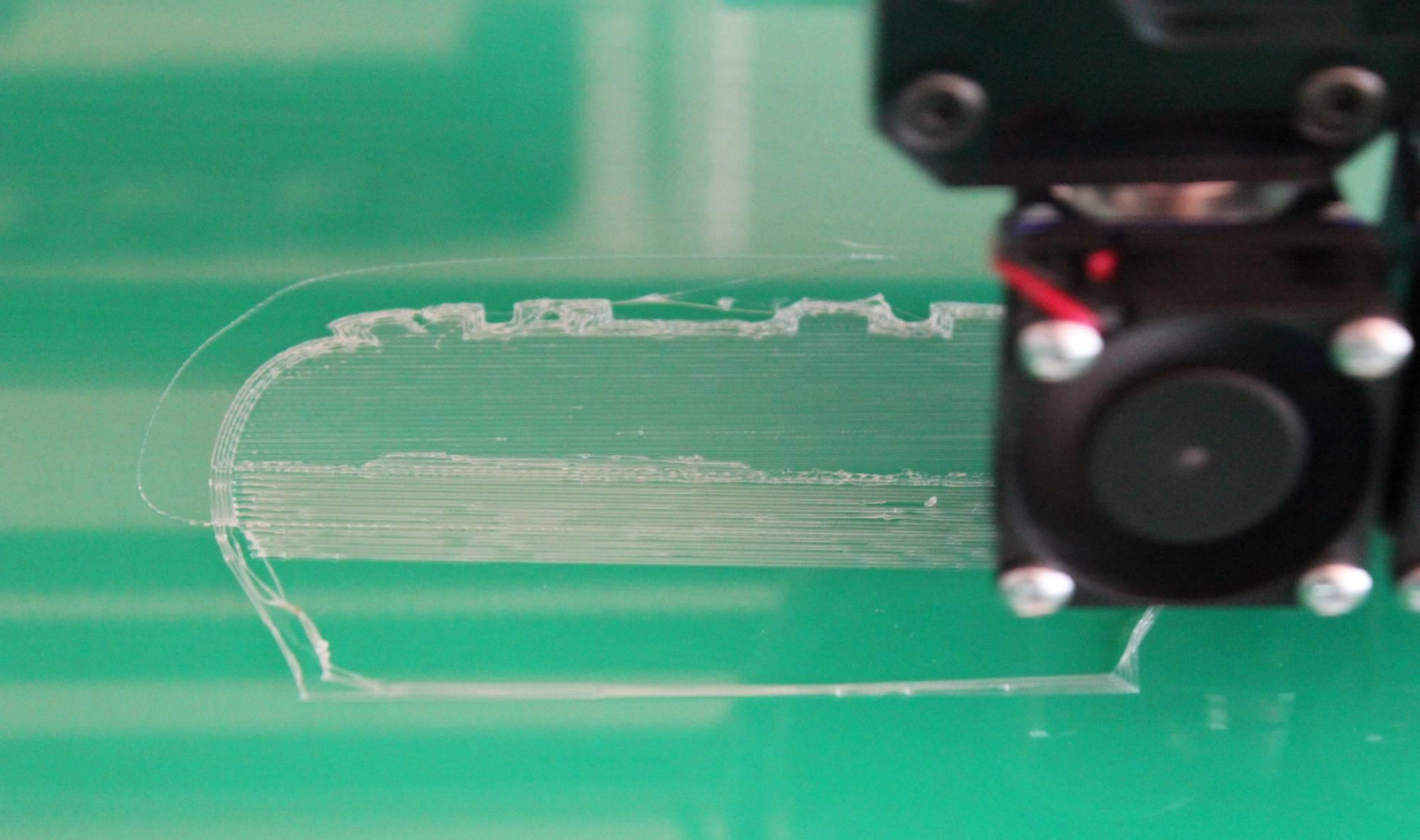
Freeware. English, Poland, Czech and other translation



Simplify3D

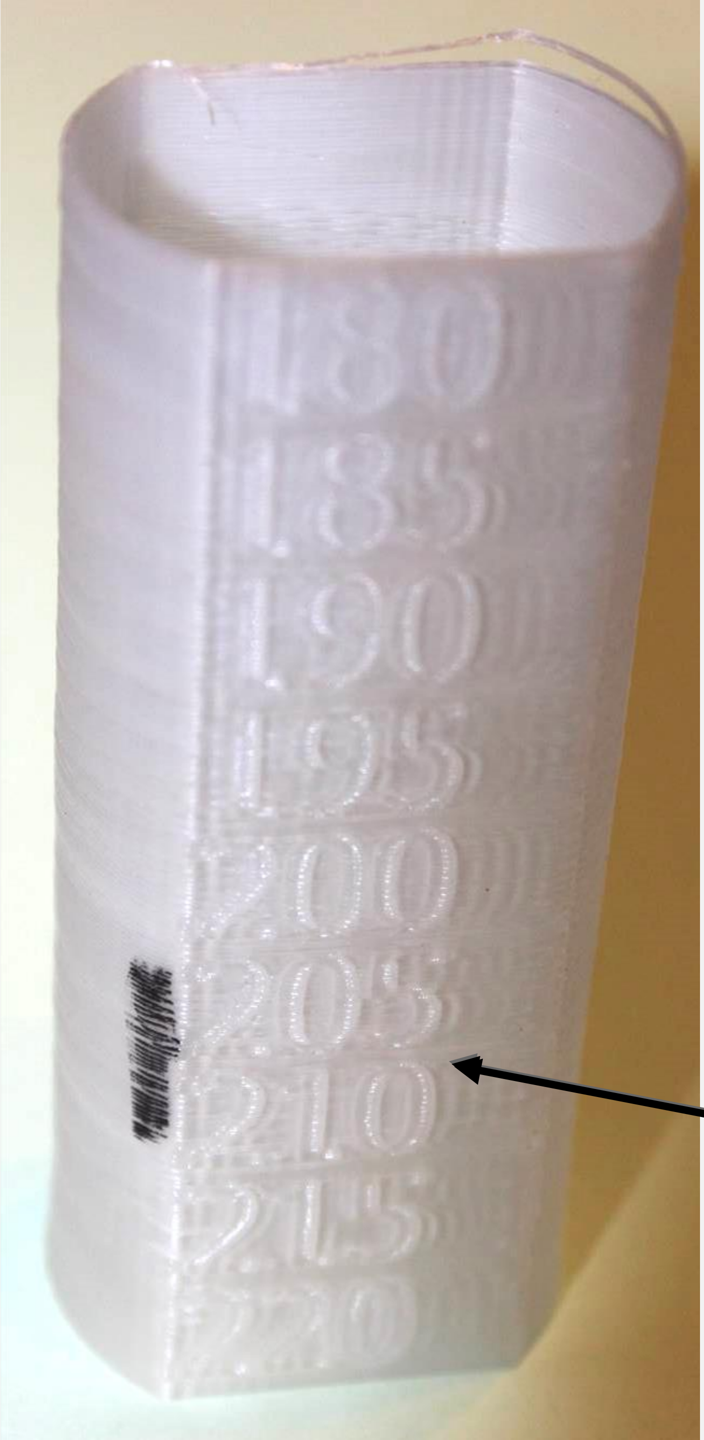
English only

Slicing by Simplify3D is faster as Repetier Host (sample: Repetier Host = 75 minutes, Simplify3D only 15 minutes !)



Hardware and firmware = „open source“ – by Arduino

Service by myself, programming by myself



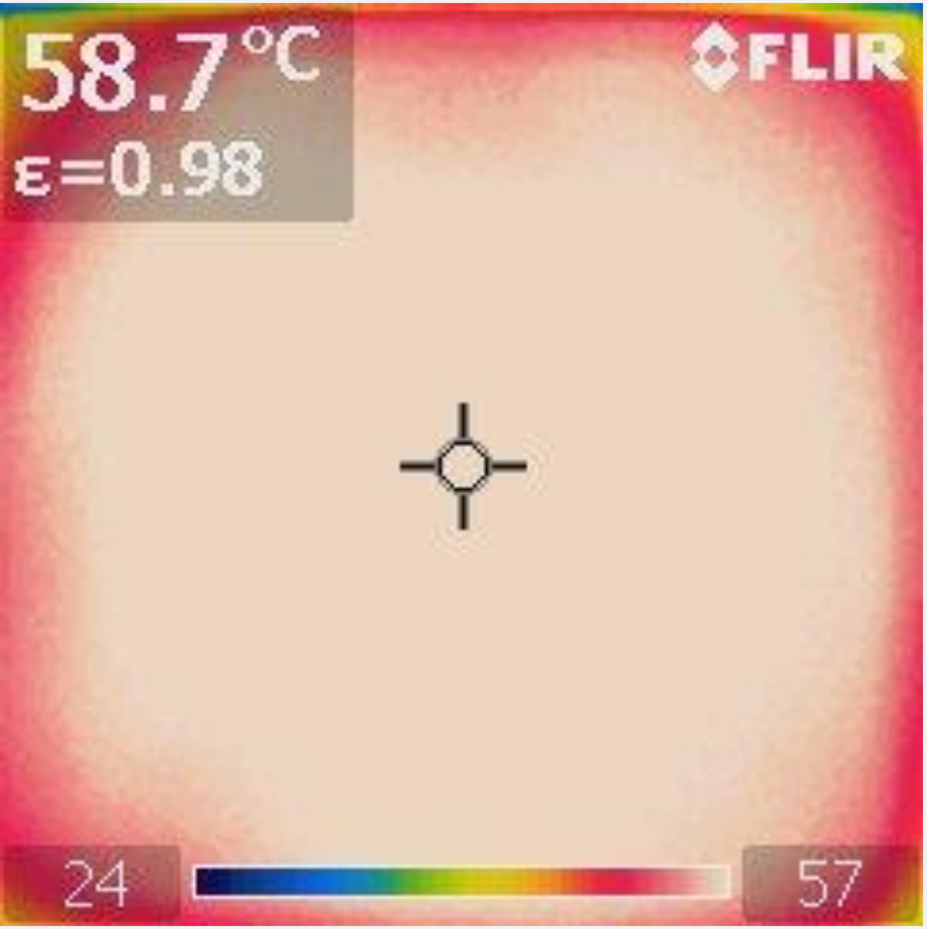
Temperature test
For specific material

A few of layers with different temperatures (change nozzle temperature setting during printing)

Search optimal temperature for obtain of best quality

Thermal measurement to verify the heated bed temperature <u>Why ?</u>

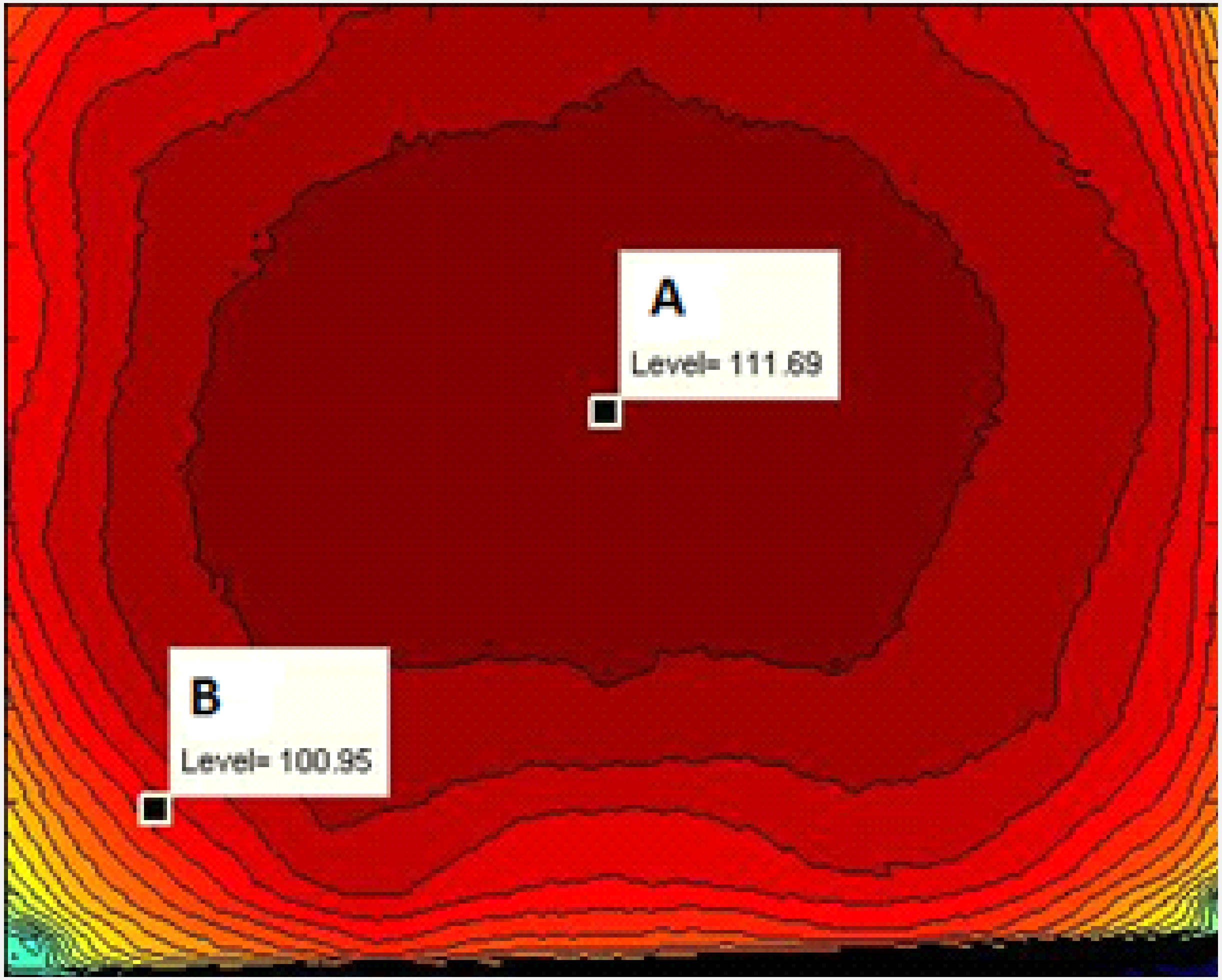
When printing with ABS, the temperature difference of 1 °C may also have a significant effect on the correct model printing.



REAL temperature at bed for bed temperature at LCD 60 °C (<u>by thermocamera</u>)

For 120 °C: the difference was up to 9 °C !

The temperature difference from the center of the heated bed to the edges was approximately 8 °C !
Not homegenous – better print in centre of heated bed



isothermal areas for temperatures set to 120 °C

For information, the verification of correct temperature distribution of heated bed by thermal imaging camera was done. On the basic experiments by thermal imaging camera, it was found the fact that the temperature difference of actual and set temperatures of a heated bed are increasing with increasing temperature. If the bed temperature is to be at real 60 °C, then setting must be approx. 6-8 °C higher, so the set temperature must be 66-68 °C. In contrast, the control of the extruder nozzles confirmed that the actual temperature is nearly such as the set temperature.

The nozzles of 3D printer have high temperature in range from 180 to 290 °C during and after printing job before the nozzles cool. There is a risk of burns during the exchange of the filament. Similarly, the heated bed may have high temperature about 120 °C.

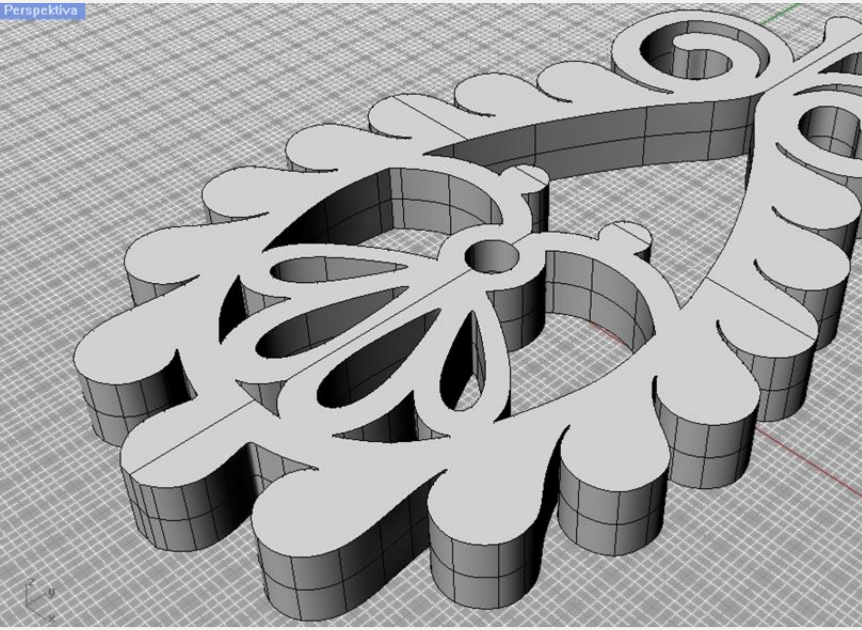
Final 3D printed technical objects

As samples of final 3D printed technical objects are

1) the earrings and ring from “wood“

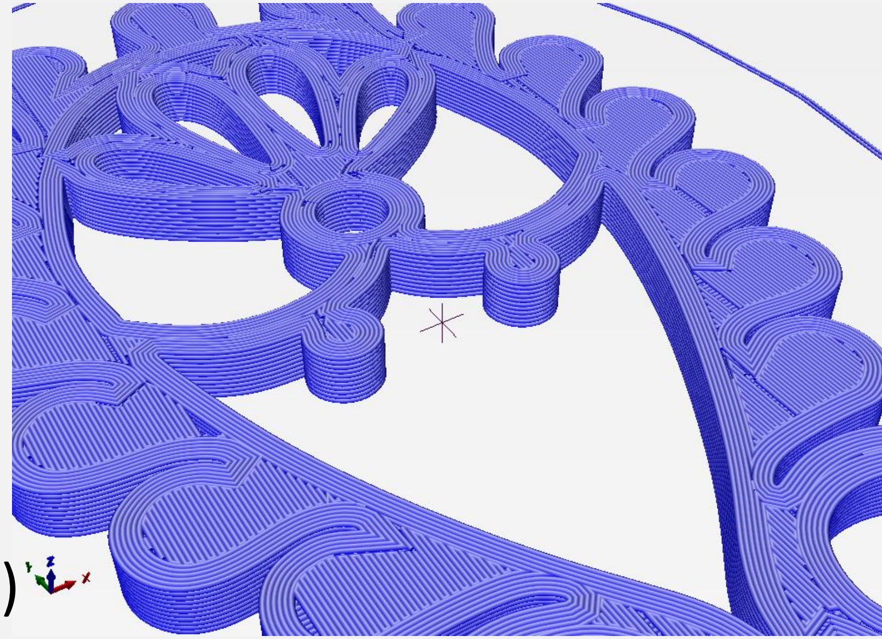
for student model collection

Material Timberfill   Print time of selected one earring was 4 hours



a)

b)



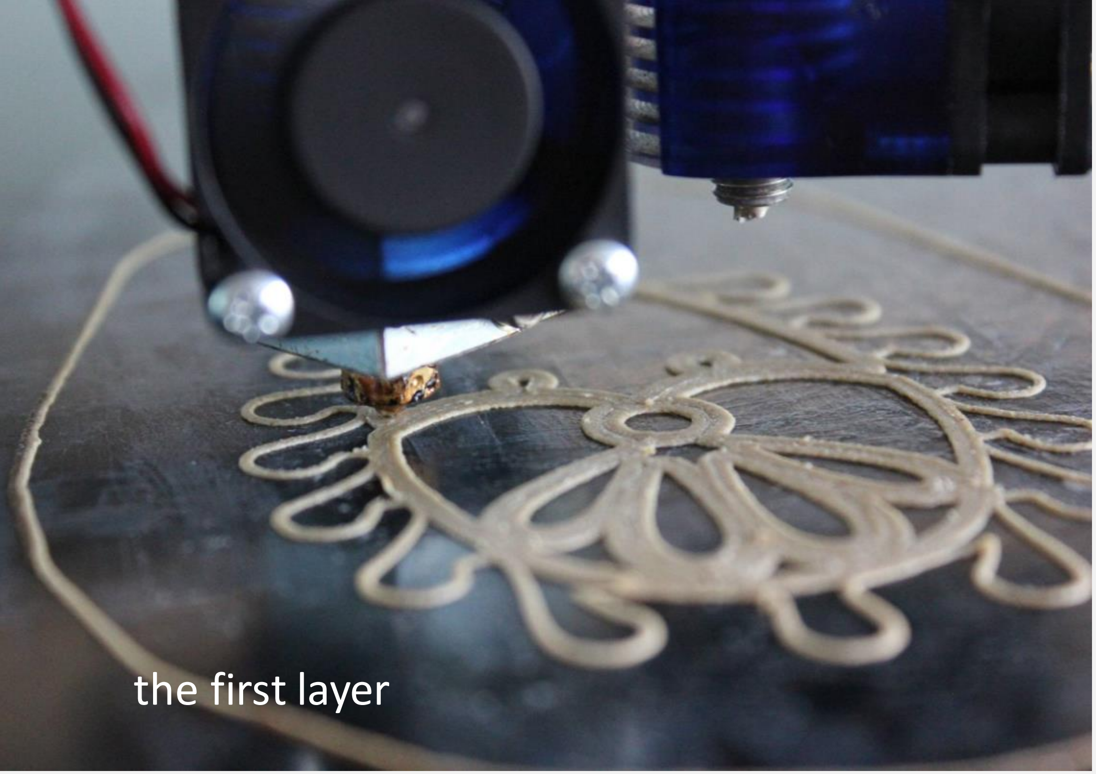
From design to printing:

a) design in Rhinoceros

b) slicing

c) printing of final layer

c)


the first layer

Final model collection

earrings and ring

Final 3D printed technical objects

2) Propeller of model of watermill from ABS

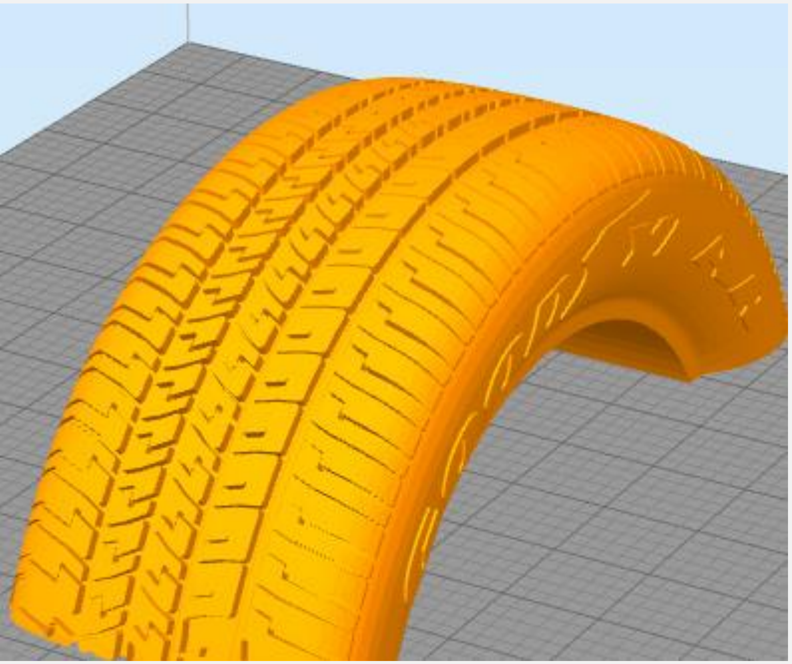
The model consist only five layers in the narrowest place of propeller and heated bed temperature had to be suitably chosen to avoid deformation of the edges of propeller during printing.

Propeller of model of watermill from red ABS (with tape measure in cm) with its use for kid stuff money-box

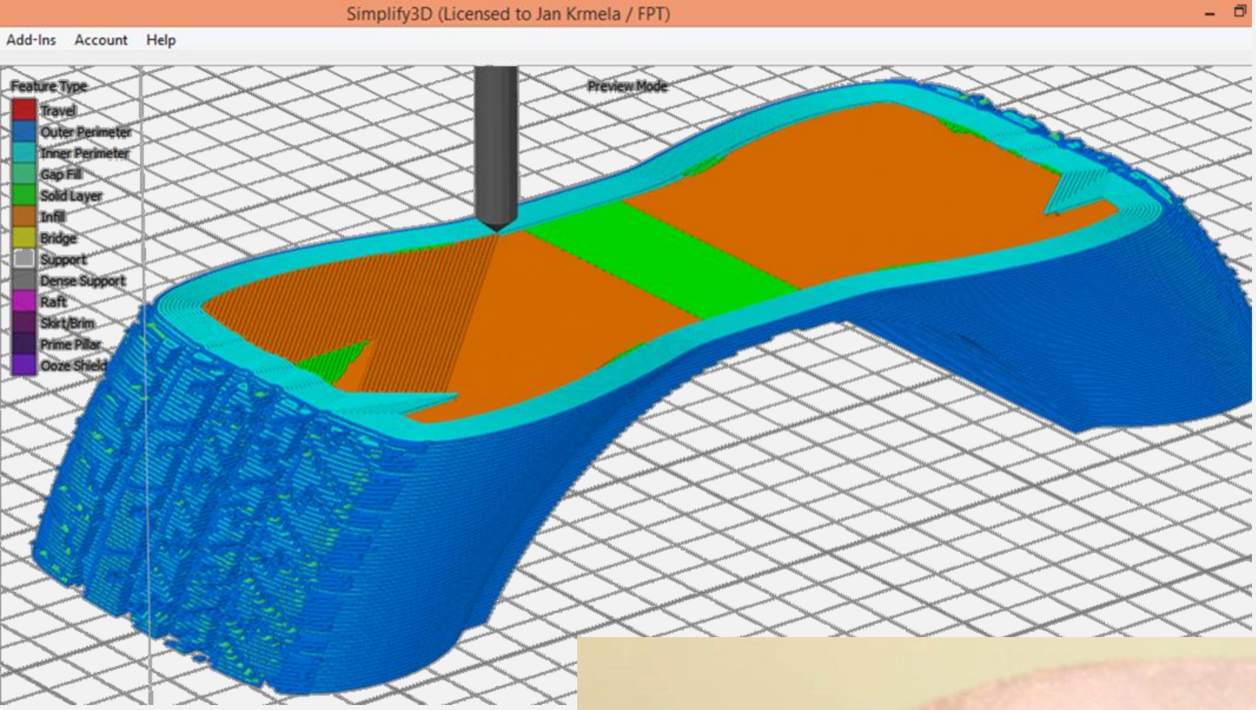
Final 3D printed technical objects

3) Miniature of specific tire model from PLA

for purpose as a teaching aid in selected technically subjects, which are oriented with oriented to composite objects and will also be used to plan experiments on static tire test equipment.



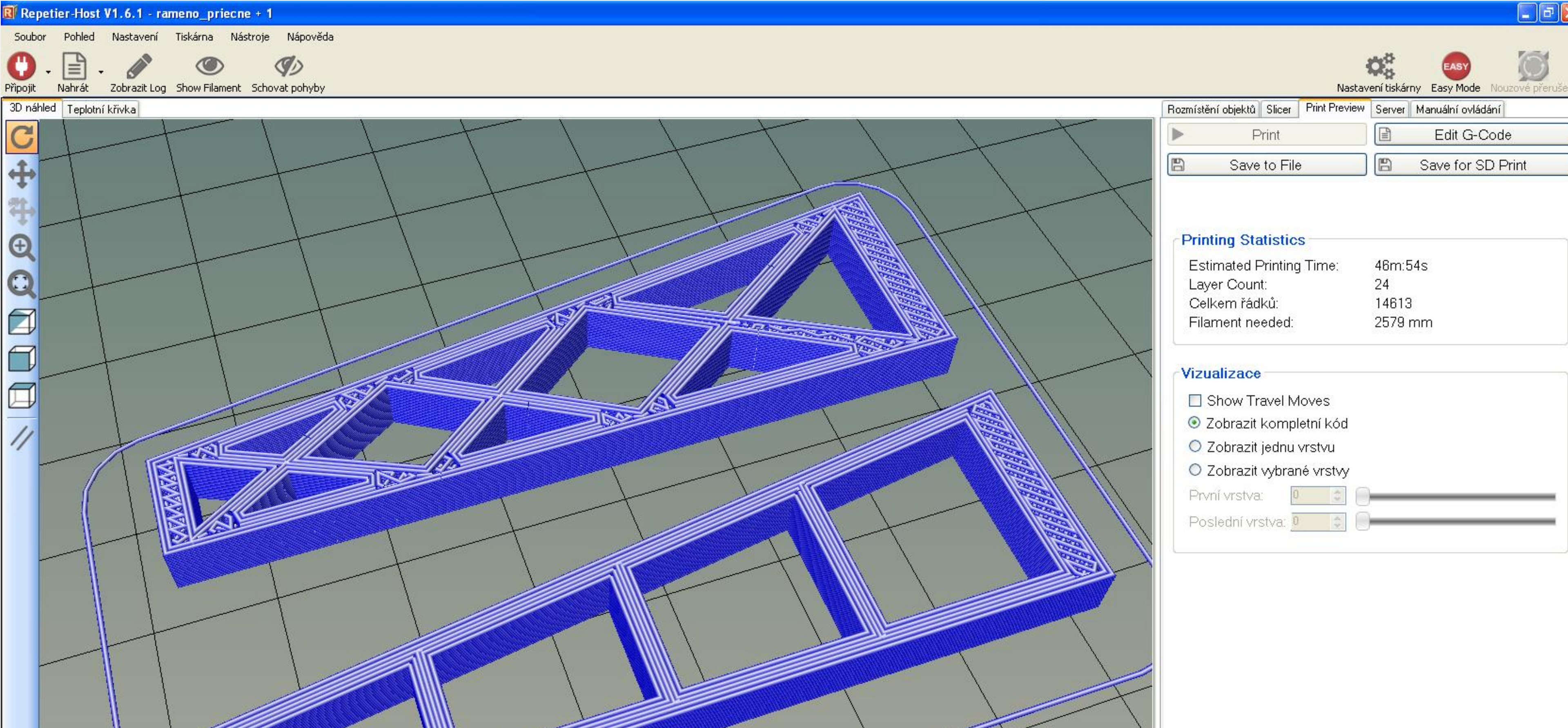
Tire model – design 3D geometry model (from internet), slicing model by Repetier Host

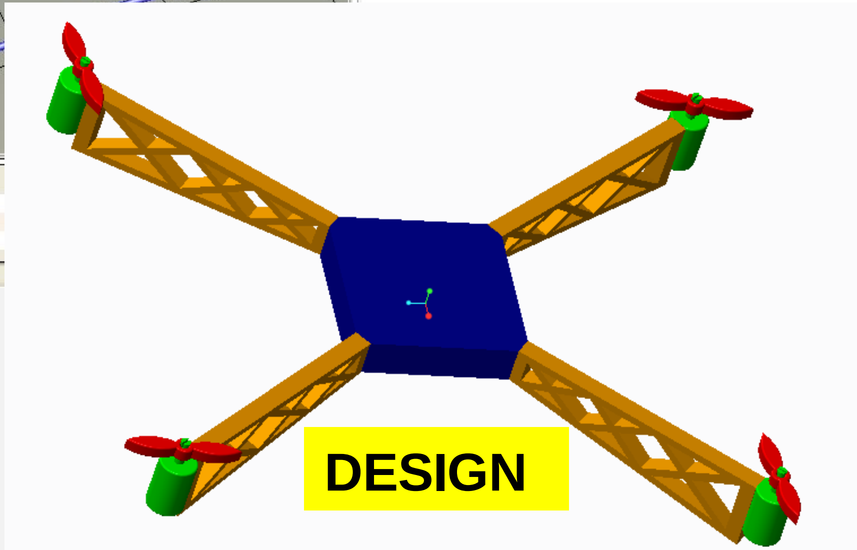


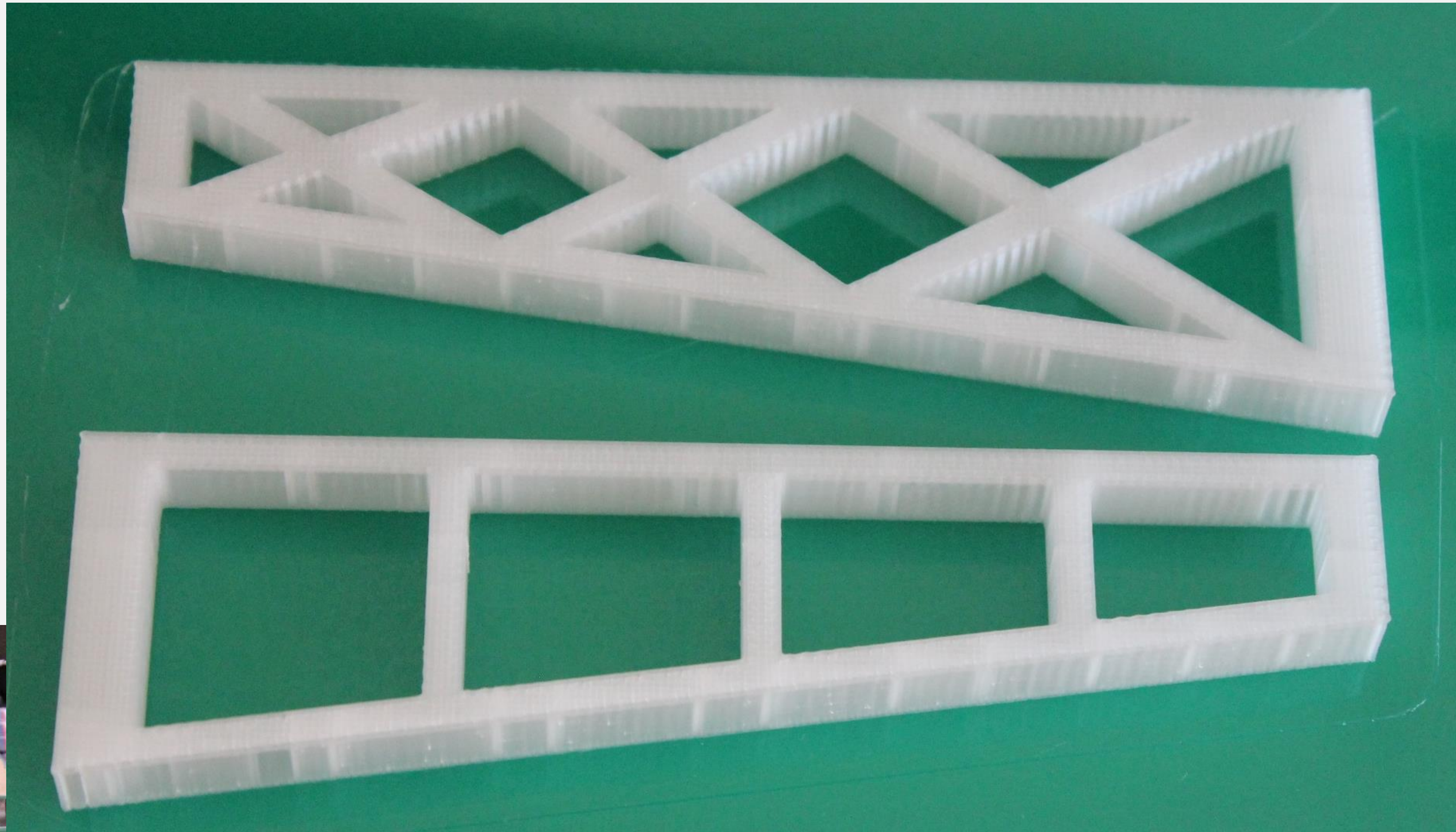
Tire model – slicing model by Simplify3D, final tire model

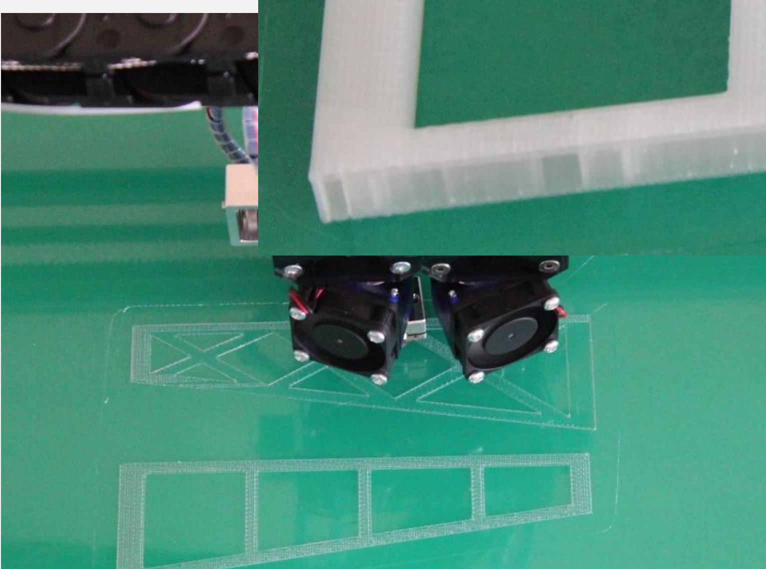
Final 3D printed technical objects

4) Part of dron from PLA


Repetier-Host V1.6.1 - rameno_priecne + 1
Soubor
Pohled
Nastavení
Tiskárna
Nástroje
Nápověda
Připojit
Nahrát
Zobrazit Log
Show Filament
Schovat pohyby
Nastavení tiskárny
Easy Mode
3D náhled
Teplotní křivka
Rozmístění objektů
Slicer
Print Preview
Server
Manuální ovládání
Print
Edit G-Code
Save to File
Save for SD Print
Printing Statistics
Estimated Printing Time: 46m:54s
Layer Count: 24
Celkem řádků: 14613
Filament needed: 2579 mm
Vizualizace
Show Travel Moves
Zobrazit kompletní kód
Zobrazit jednu vrstvu
Zobrazit vybrané vrstvy
První vrstva:
Poslední vrstva:
Zobrazit v logu:
Příkazy
Informace
Varování
Chyby
ACK
Automatický posun
Vyčistit Log
Kopírovat
21:36:01.500 <Slic3r> => Exporting G-code to composition.gcode
21:36:02.484 <Slic3r> Done. Process took 0 minutes and 2.594 seconds
21:36:02.484 <Slic3r> Filament required: 2579.1mm (6.2cm3)
Odpojeno: default


DESIGN





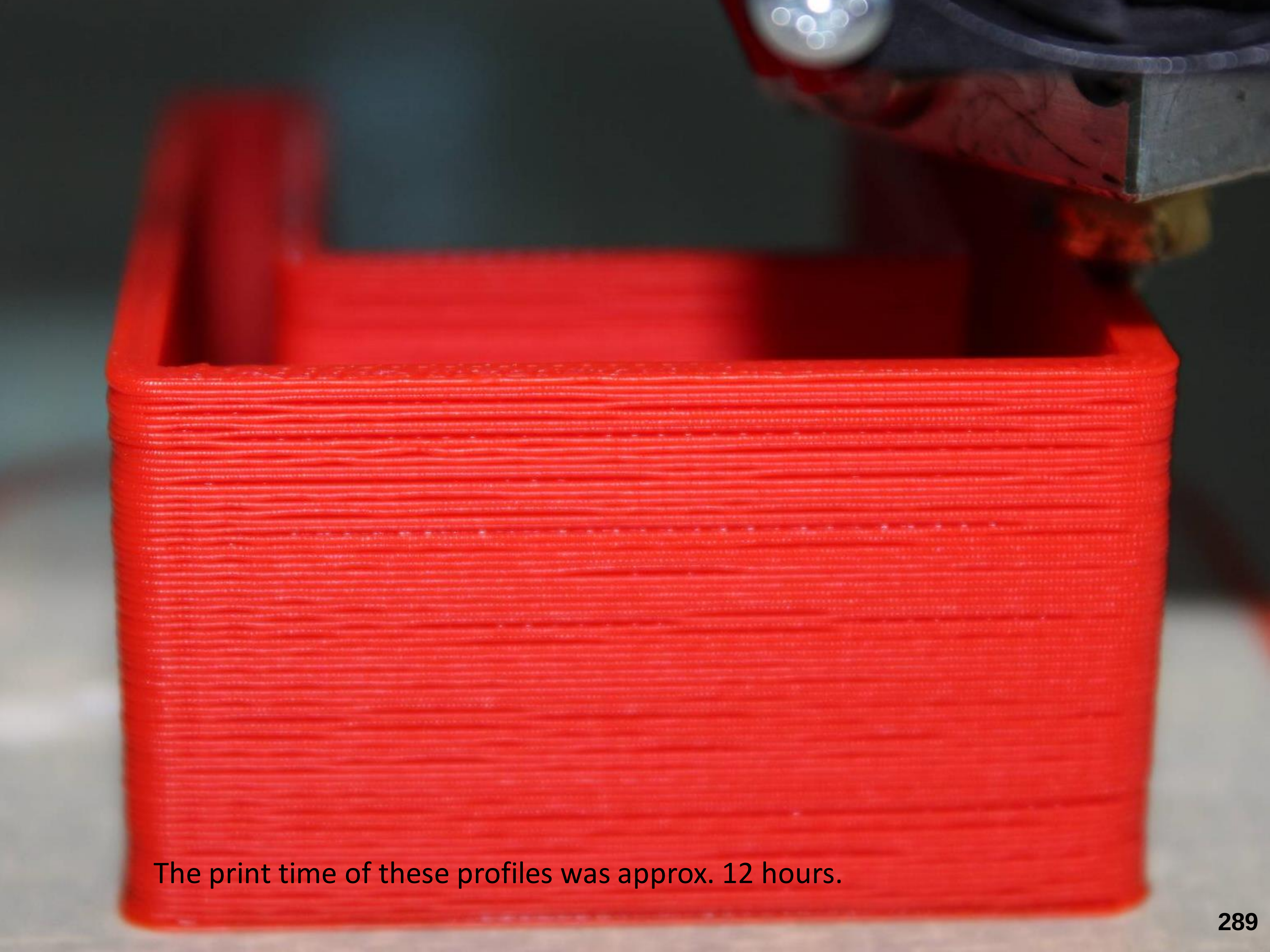
FINAL SHOULDER OF DRON

Final 3D printed technical objects

5) High profiles from PLA

By control programs the printing of some parts altogether but sequentially is possible.
As sample the two same profiles:
the first step = the entire one profile was printed,
the second step = after whole first profile printed the second profile was printed.
Printing takes place as a **single G-code file**, but **printing of the profiles takes place sequentially**!

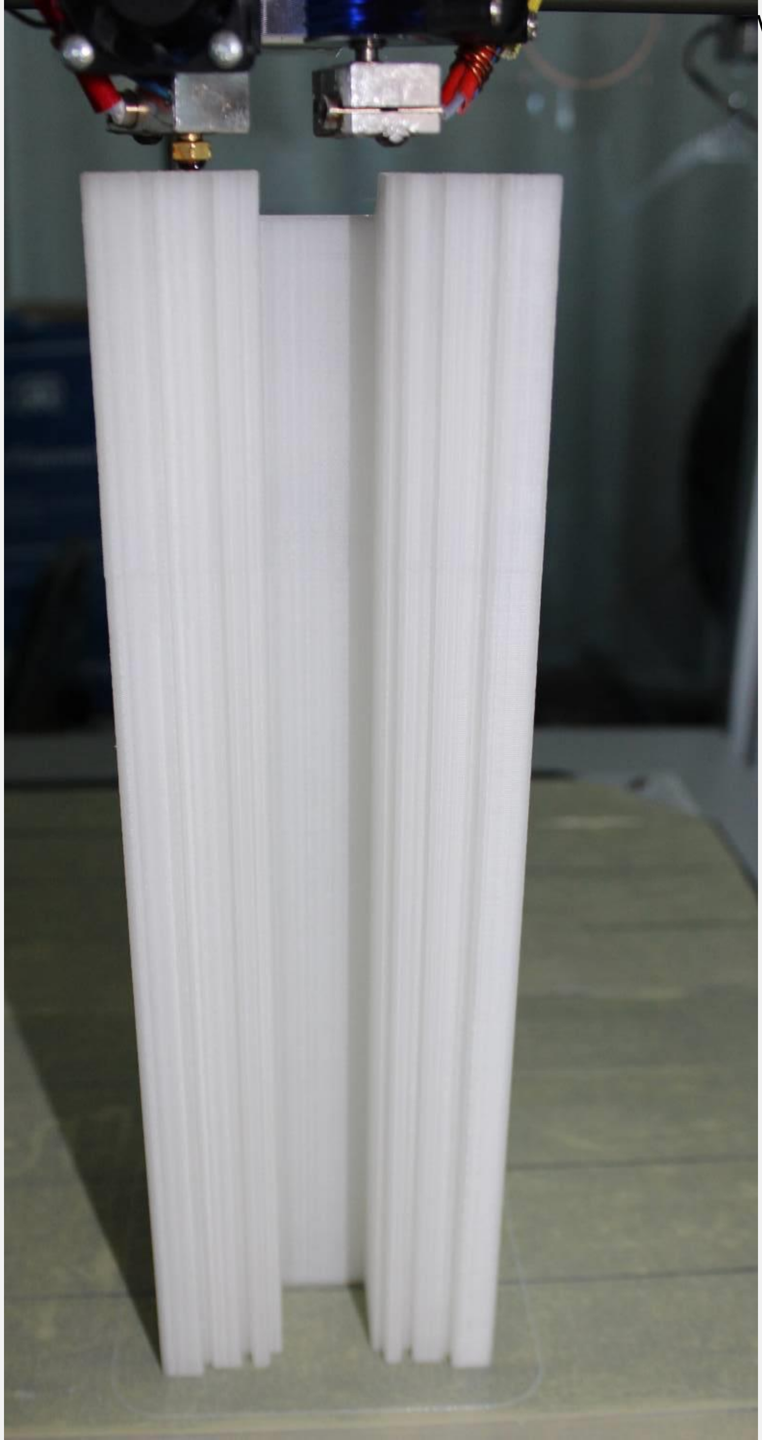
The profiles have high of 200 mm. The G-code was optimized for obtaining of **short print time** and **good quality**!
The dimensional accuracy is ± 0.1 mm !

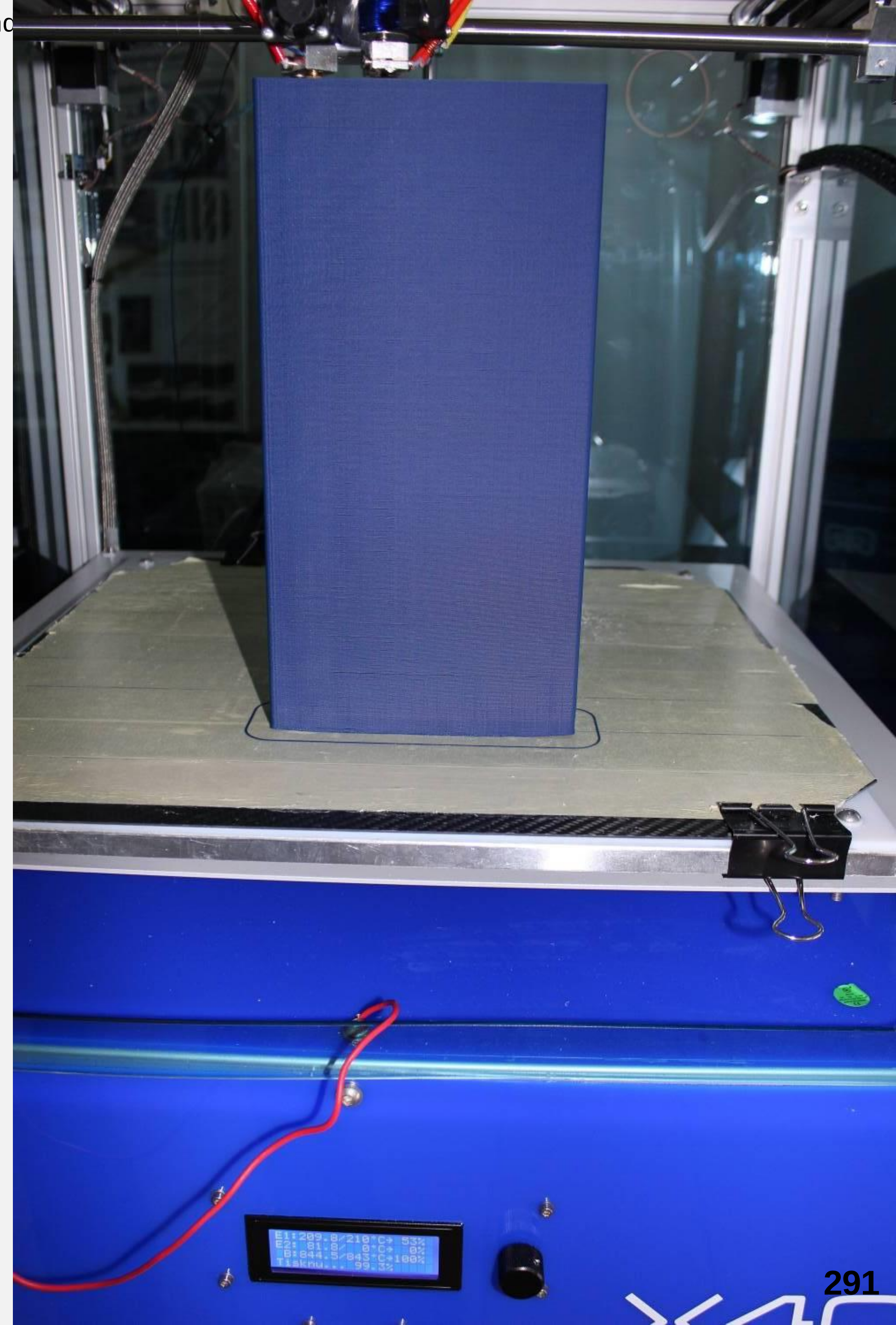


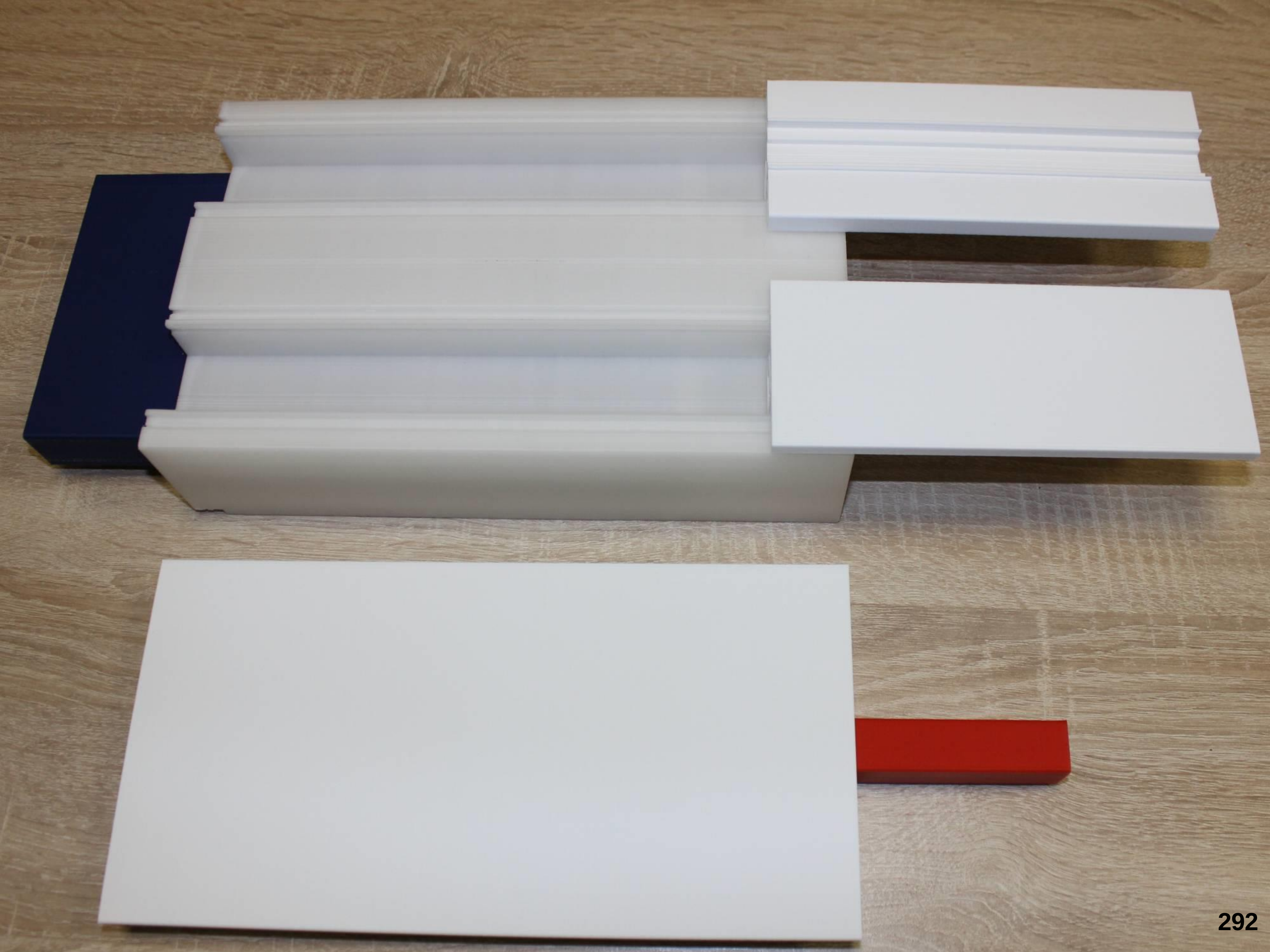
The print time of these profiles was approx. 12 hours.

The other big profiles had **high of 300 mm**, almost the whole height of build platform is used. Sometimes the print time was **over 50 hours** per one profile only.

3D printing can sometimes be labeled as **not quickly** production but production requiring longer production times.



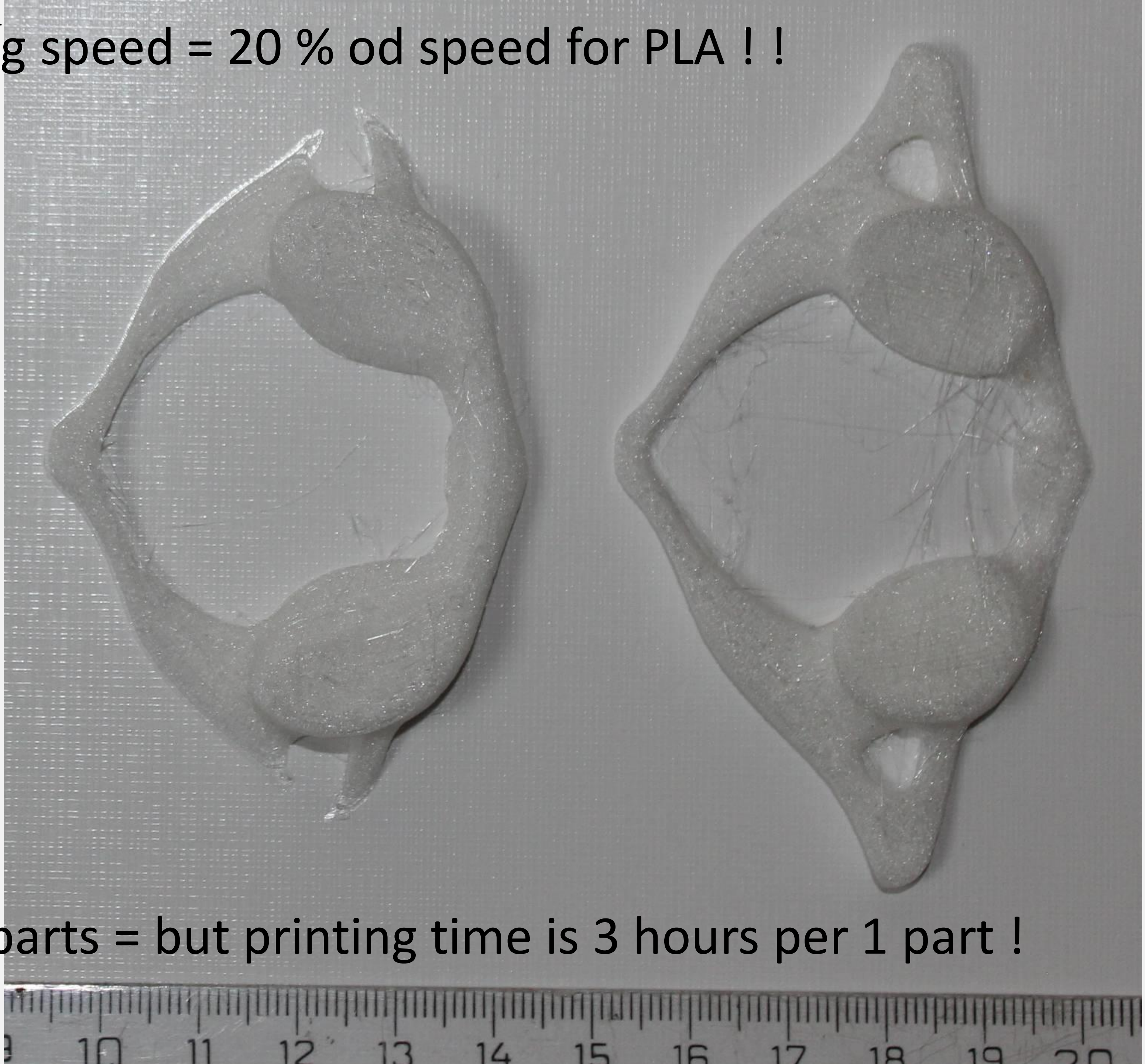




Final 3D printed technical objects

6) Dress accessories from special flexible material FLEXIFILL

Printing speed = 20 % od speed for PLA ! !

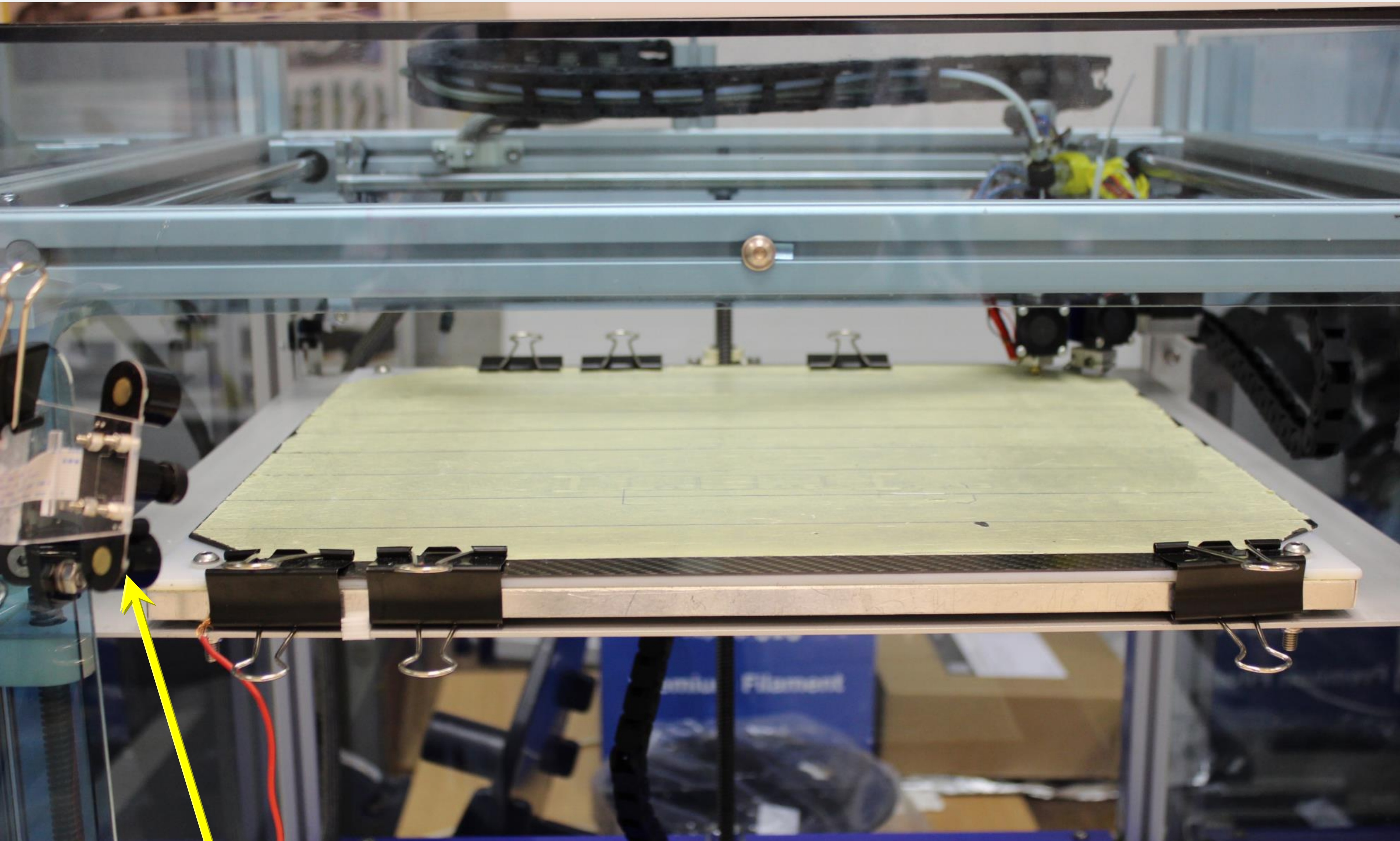


Small parts = but printing time is 3 hours per 1 part !

VIDEOS (see attachment):

- **Ear-ring (No. 2)**
- **Dress accessories (No. 3)**
- **Profiles (No. 4)**
- **3d print of protective face shields for paramedics (No. 5, 6)**

- **<u>In future: print with two materials elastic and hard = composite</u>**



Online printing an online monitoring by infra camera

- 1) If the heated bed temperature sets on 100 °C for ABS, the actual measurement would be only 92 °C. A minimum heated bed temperature about 109 °C for the ABS, which actually corresponds to only 100 °C.
- **2) The nozzles have high temperature.** There is a risk of burns during the exchange of the filament. Similarly, heated bed temperature 120 °C may be used.
- Ensure increased safety during 3D printing. There is a risk of injury by moving parts, on which extruders are of 3D printer.

- **3) The optimum print settings** (especially print speed, layer thickness, temperature) are needed to **search to avoid defects and print errors for obtain of good quality.**

- 4) In the future we plan printing **with two materials** simultaneously for purpose **creating composites** not only for educational process. The 3D printing of two materials is contemplated in order to produce a part of the composite incorporating, filament Carbon20.

THE SAFETY DURING 3D PRINTING OF TECHNICAL OBJECTS

Summary

The part deals with 3D printing of technical objects at 3D printer GERMAN RepRap X400. This printer is designed for large format industrial 3D printing. The part focuses on technology of 3D printing, preparing of geometrical 3D model for printing with use freeware Repetier Host and commercial software Simplify, comparing these programs, setting the parameters for 3D printing from the perspective of quality of printed objects and 3D printer control from afar with using software Repetier Server or other freeware. It is possible printing with different materials, not only standard ABS and PLA. The printer has DD3 Dual extruder. The extruders can be heated to 290 °C. Maximum temperature of heated bed is 120 °C. Printing Plate Carbon is used for 3D printing or other preparing pad. This part also includes verification of correct temperature distribution of heated bed by thermal imaging camera. On the basic experiments by thermal imaging camera, it was found the fact that the temperature difference of actual and set temperatures of a heated bed are increasing with increasing temperature. If the bed temperature is to be at real 60 °C, then setting must be approx. 6 °C higher, so the set temperature must be 66 °C. In contrast, the control of the extruder nozzles confirmed that the actual temperature is nearly such as the set temperature.

Key words: *3D printing, PLA, temperature, setting, control*

Introduction

At present, the rapid advances in technology and, in particular, their use in a wide range of industries. One of the modern methods is 3D printing, in which the virtual model is printed in its real form using various 3D printing technologies. 3D models can be printed from different types of materials such as thermoplastics, metals, glass, elastomers, ceramics, etc. 3D printing is becoming increasingly popular in areas such as engineering, construction, automotive, medicine, electronics, science, research. The Faculty of Industrial Technologies in Púchov has since 2016 a new 3D printer GERMAN REPRAP X400, namely the version Pro Pro V3 (Figure 1), which is based on the Fused Deposition Modeling (FDM) method (sometimes the abbreviation FFF is used).

FDM technology is currently the most used technology for 3D printing. Data obtained from a 3D design of the stl format (e.g. 3D object, which created by SolidWorks or Rhinoceros or other programs, is export as stl format) is imported into program such as Kisslicer, in which parameters such as selected of support type, type of device, model fill method, layer thickness, or model orientation in the printer's workspace are setting. The output from the program is special file G-code format for 3D printer.

It uses thermoplastic material (ABS, polycarbonate, elastomer, wax, etc.) in the shape of a filament that is unwound from the storage coil. In the nozzle, the building material is heated to the desired temperature and the molten material is passed through the nozzle opening. This system is set to a temperature slightly higher than the melting temperature of the thermoplastic material. From the nozzle outgoing material are combined to form the desired thin layer which quickly solidifies.

The nozzle moves in the coordinate axes X and Y and applies the individual layers. After applying one layer, the heated bed position drops by a value equal to the layer thickness of the model. Sometimes a support material is required for the model.

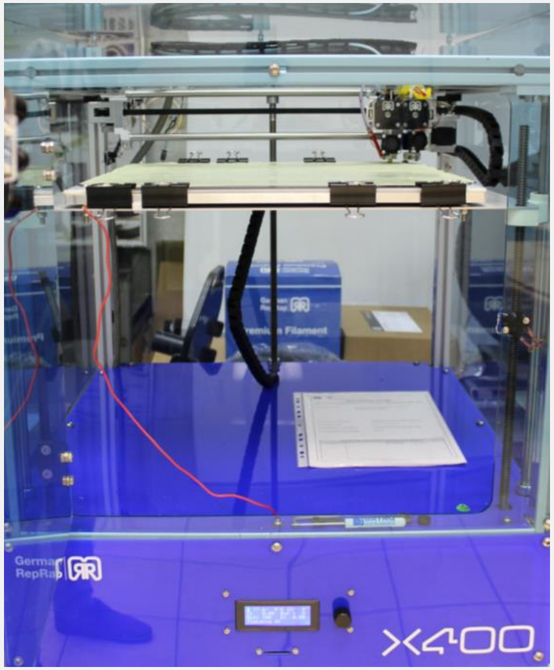


Figure 1. 3D printer German RepRap X400

FDM benefits include lower operating costs and the cost of models, the possibility of using a large number of materials. Extruded models are characterized by good strength and shape-stable construction, which is suitable for mechanical use of models. The disadvantages of FDM are slower production of full parts of the model (print time is in hours) and less accuracy which is limited by the shape and diameter of the nozzle. Selected FDM 3D printing materials are shown in Figure 2. The choice of material depends on the use of the printed object. Each material has different mechanical properties (tensile strength, bending strength).

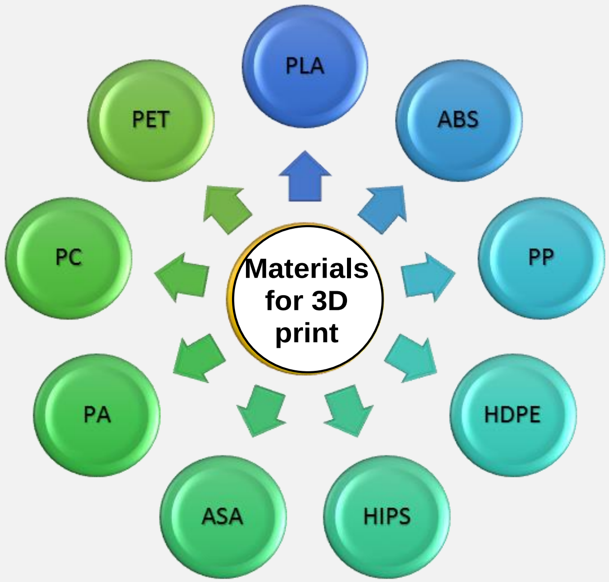


Figure 2. Materials for 3D print (ASA – acrylonitrile styrene acrylate, PA – polyamide, PC – polycarbonate, PET – polyethylene terephthalate, PLA – polylactic acid, ABS – acrylonitrile butadiene styrene, PP – polypropylene, HDPE – high density polyethylene, HIPS – high-impact polystyrene)

1. Parameters of 3D printer

Filament with a diameter of 1.75 mm is used for 3D printing. The build platform is 390 x 400 x 326 mm. The printer has DD3 Dual extruder (Figure 3). The DD3 extruder developed by German RepRap features two print heads, thus allowing printing in two colors or with water soluble support material such as PVA (polyvinyl alcohol) for PLA or HIPS for ABS parts. Exchangeable nozzles with diameters of 0.25; 0.40; 0.45; 0.60 and 0.80 mm are used. The nozzle with diameter 0.40 mm is most used. The 3D printer can be operated via an LCD display [1] with an SD card reader (Figure 4). The 3D printer includes electronic board Arduino Mega 2560 with Ramp 1.4.2 inside. The change of all parameters is possible via open Adurino by notebook.

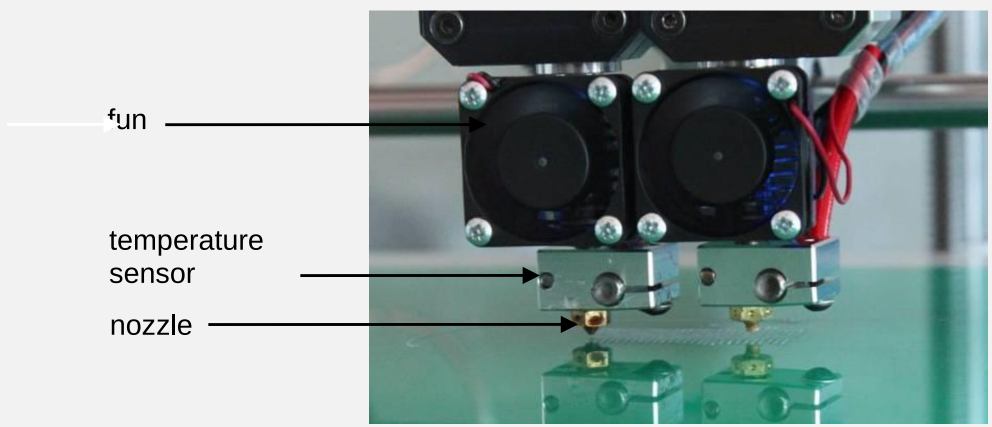


Figure 3. Dual extruders (2 nozzles)

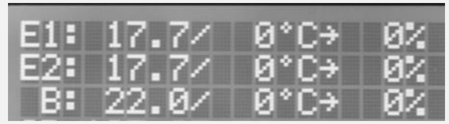


Figure 4. LCD display of 3D printer with displaying of actual nozzle temperature values (marked as E1 and E2) and heated bed temperature value (marked as B)

Source: own research.

The other important technical parameters of 3D printer GERMAN REPRAP X400 are shown in Table 1.

Table 1 Technical parameters of 3D printer [2]

Distance between nozzles	29.95 mm
Minimum layer height	0.1 mm
Print speed	10–150 mm/s
Travel speed	10–300 mm/s
Dimensions	700 x 700 x 770 mm (height)
Weight	55 kg

Source: X400 PRO 3D printer [online]. Available on: https://www.germanreprap.com/en/products/3d-printer/x400-pro-3d-printer/.

Print filaments are currently available from these materials: PLA, ABS, Timberfill, ASA and flexible filament Flexfill 98A (each material in at least two color shades) and as support materials HIPS and PVA. Timberfill is made of biodegradable wood-based material. A carbon pad is used for printing. If PLA is used for printing, then nozzle temperature is 210 °C and heated bed temperature is 60 °C according to the data by producer of specific PLA material.

Ensure increased safety during 3D printing. There is a risk of injury by moving parts, on which extruders are of 3D printer. There is a risk of burning with a hot nozzle, for example, when changing the filament and adjusting the pad.

2. Process for data preparing for printing

The geometry of the 3D models is to be exported to the stl format. Consequently, a so-called “slicing” process must be performed, which means that 3D model in stl format will be divided by the horizontal cuts that are needed to generate the code for the extruder moves. Various programs can be used for slicing (such as Cura, Kisslicer, Slic3r, Repetier-Host, Simlify3D), which can be connected to your computer printer via the USB interface to control the printer directly. Simplify3D (commercial version) and Repetier-Host (free open source program) were tested from the list of programs.

Repetier-Host (with modified printer parameter setting by the printer manufacturer) includes almost all of the features available in other programs. It includes "slicers" as well as control tools for 3D printer (Figure 5). It can also be used for both extruders. Its advantage is the disposition of the English, Poland, Czech and other translation.

On the other hand Simplify3D is in English only (Figure 6 is view on slicing geometry). Both programs complement each other with print settings. Repetier-host includes Slic3r [3] for generating G-code file for 3D printer. The change parameters with change height are possible by other slicing program. Slicing by Simplify is faster as Repetier-Host.

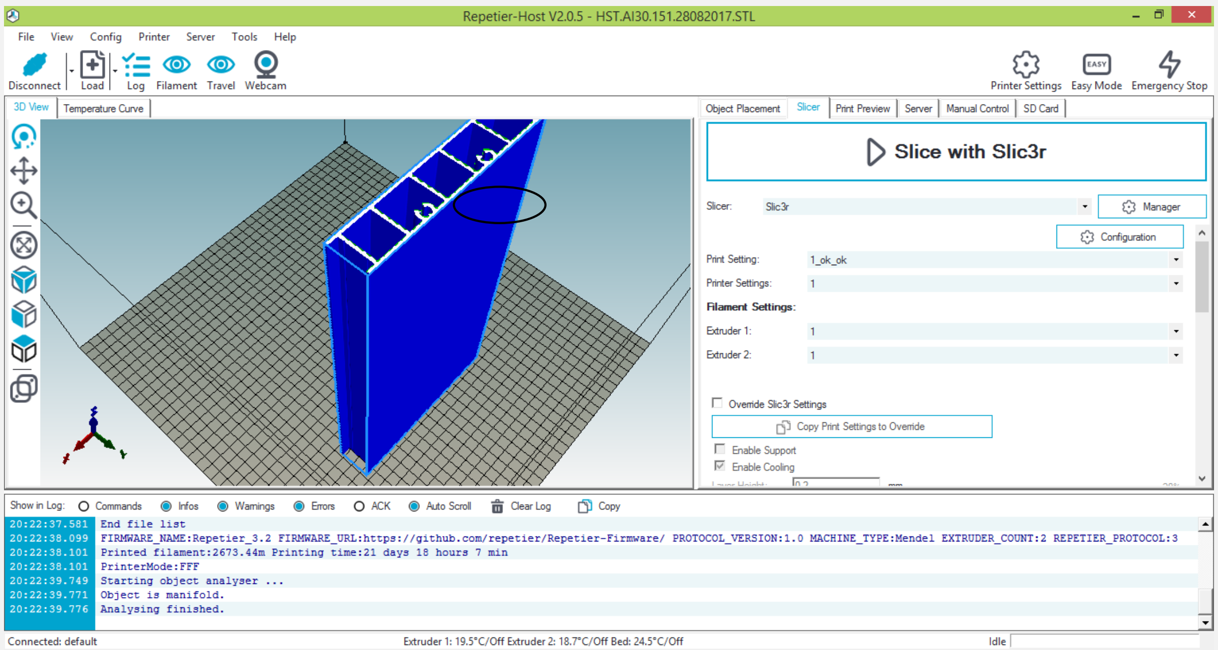


Figure 5. Repetier-Host with slice parameters

Before generating of G-code the price of print per hour and price of material give to setting for obtaining of final price of printed part. Also sometimes the repairs of geometry of 3D object for printing had to use. The program Netfabb Basic is very simply and quickly program for repair of geometry. Also the setting of parameters such as extrusion width, retraction speed, layer height, infill, nozzle temperature, heated bed and other important parameters are necessary choose appropriately (Figure 7). E.g. the extrusion width is 0.35 mm for nozzle with diameter 0.40 mm for specific material.

After generating of G-code the information about print time, volume of materials, weight and namely price for material are obtained, see Figure 8.

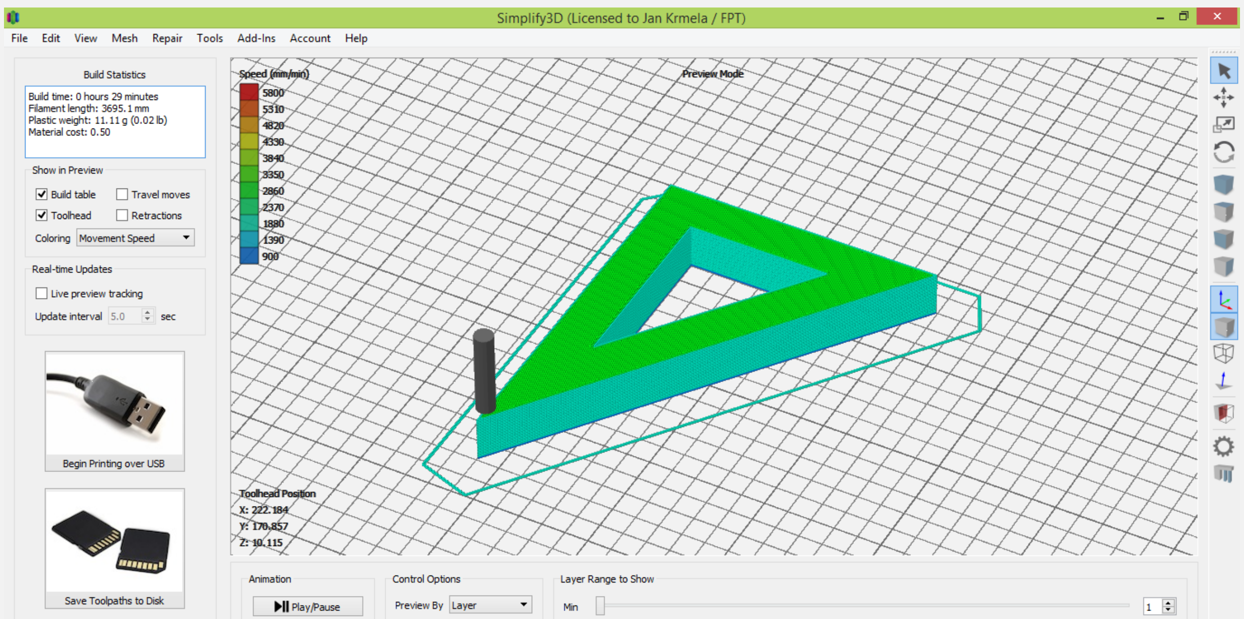


Figure 6. Simplify3D environment

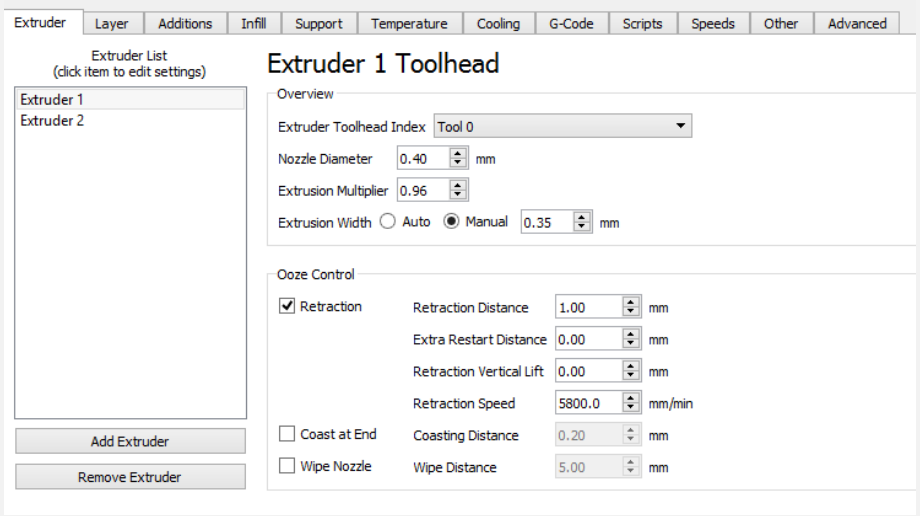
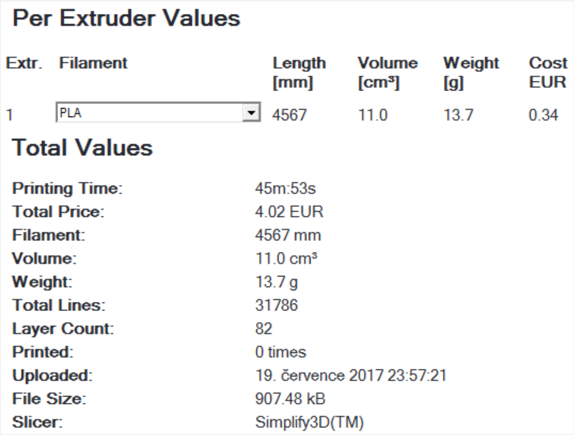


Figure 7. Setting of printing parameters by Simplify3D



Per Extruder Values

Extr.	Filament	Length [mm]	Volume [cm³]	Weight [g]	Cost EUR
1	PLA	4567	11.0	13.7	0.34

Total Values

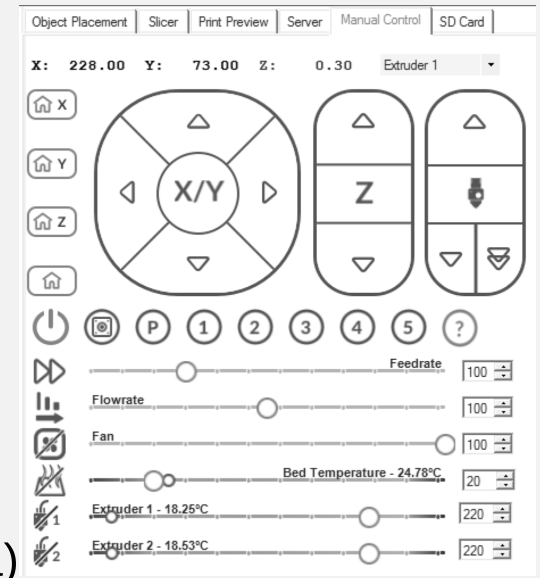
Printing Time:	45m:53s
Total Price:	4.02 EUR
Filament:	4567 mm
Volume:	11.0 cm³
Weight:	13.7 g
Total Lines:	31786
Layer Count:	82
Printed:	0 times
Uploaded:	19. července 2017 23:57:21
File Size:	907.48 kB
Slicer:	Simplify3D(TM)

Figure 8. Information about technical object for 3D printing from Repetier-host

3. Control of 3D printer

The 3D printer GERMAN REPRAP X400 is equipped with a SD memory card slot with full print process control over the LCD and LCD output control parameters in the English or other languages such as Czech. The generated G-code can then be uploaded to a memory card and the print process can be started without the need for computer using.

An optional network connection via Ethernet and Wifi as well as browser-based control and print monitoring via webcam are possible by 3DPrintBox which on the base Raspberry Pi with operating software from producer of 3D printer. Raspberry Pi runs on AstroPrint or Octoprint which were use for comparison too. Thus, in on-line mode on a computer, for example, in the office or at home (observation from long-distance), it is possible to check the whole process of printing and watch printing by camera. 3D printer panel control from afar with using software Repetier-Host via software Repetier-Server is on the Figure 8.

a) 

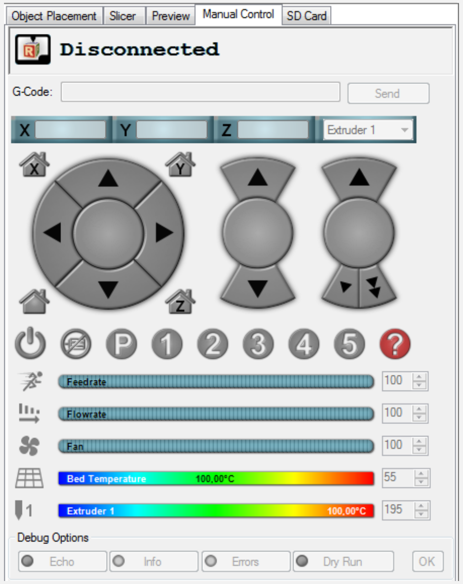
b) 

Figure 8. On-line control panel in Repetier-Host – a) new of program and b) old version

4. Thermal measurement to verify the heated bed temperature

The 3D printer has a pad that can be heated while printing 3D models. Heating the pad to the desired temperature is very important when using thermoplastics that tend to peel away from the pad. Temperatures for selected materials for 3D printing are in Table 2.

Table 2 Temperatures for selected materials for 3D printing

Material	Temperature of nozzle [°C]	Heated bed temeperature [°C]
ABS	220–240 (245*)	80–100 (115*)
PLA	190–210	60 (65*)
Flexifill 98A	200–220	30–50 (70*)
Timberfill	170–185 (195*)	40–50 (65*)

* Temperature change of the washer based on the test print for specific materials

When printing with ABS, the temperature difference of 1 °C may also have a significant effect on the correct model printing. A thermal imaging camera was used to verify the temperature of the heated bed temperature. Heated bed temperature measurements were made at 60, 80, 100 and 120 °C. These temperatures were set directly on the 3D printer. E.g. at 120 °C, the difference between the actual and the set temperature was up to 9 °C [4], see thermogram on the Figure 9. The temperature difference from the center of the heated bed to the edges was approximately 8 °C, see Figure 10. As well as controlling the heated bed temperature, control of the extruder nozzle temperature was performed.

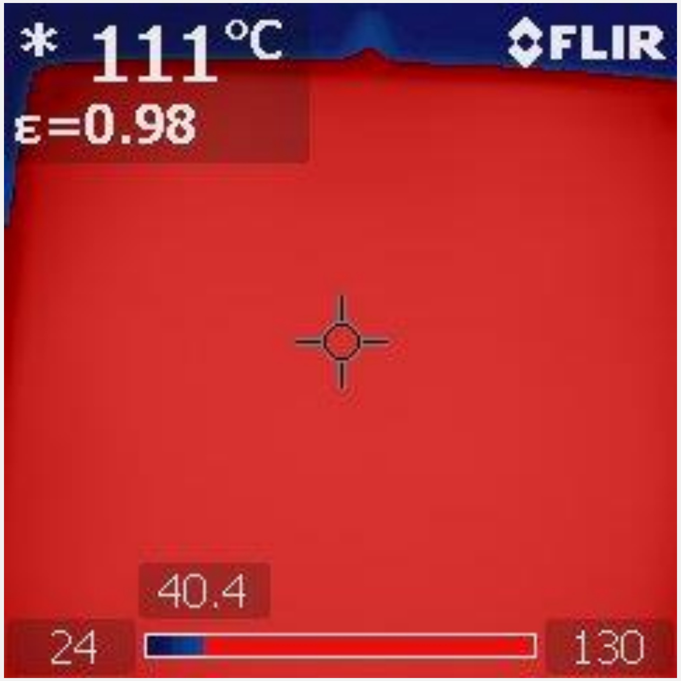


Figure 9. Heated bed temperature – comparison between temperatures set to 120 °C at display and real state on heated bed (thermogram on the right)

Source: Pajtáš M.: *3D printing for technical applications and design software extension for the PRINTER GERMAN RepRap X400* (*3D tlač pre technické aplikácie a návrhy softwarového rozšírenia pre tlačiareň German RepRap X400)*, Bachelor work, supervisor: Krmela J., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2016, 62 p., in Slovak.

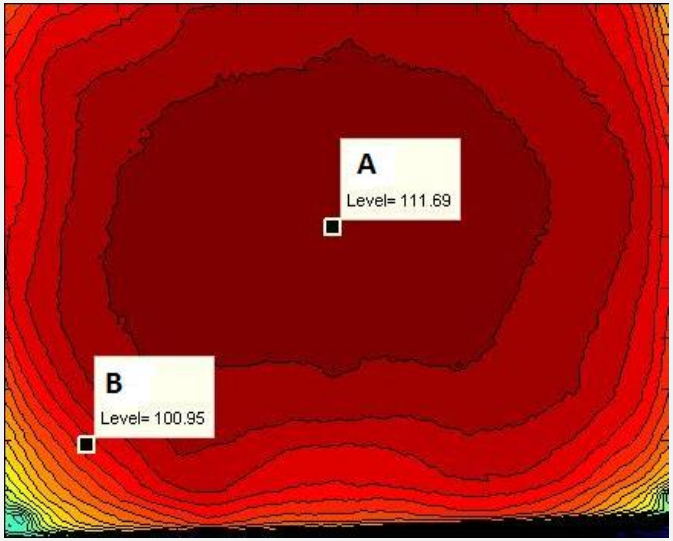


Figure 10. Heated bed – isothermal areas for temperatures set to 120 °C

Source: Pajtáš M.: *3D printing for technical applications and design software extension for the PRINTER GERMAN RepRap X400* (*3D tlač pre technické aplikácie a návrhy softwarového rozšírenia pre tlačiareň German RepRap X400)*, Bachelor work, supervisor: Krmela J., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2016, 62 p., in Slovak.

On the basic experiments by thermal imaging camera, it has been found that the difference with actual and adjusted temperatures increases with increasing temperature. If the bed temperature is to be at real 60 °C, then setting must be approx. 6 °C higher, so the set temperature must be 66 °C. It is therefore advisable to use heated bed temperature 62 °C for PLA, and a minimum heated bed temperature about 109 °C for the ABS, which actually corresponds to only 100 °C. In contrast, The printing temperature was verified of special G-code (from producer of printing), which has layers with different temperatures (change nozzle temperature setting during printing), see Figure 11.

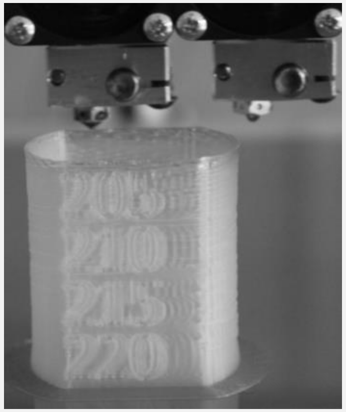


Figure 11. Layers with different temperatures

5. Final 3D printed technical objects

As samples of final 3D printed technical objects are the earrings and ring for model collection on the Figures 12 and 13. Print time of selected one earring on the Figure 12 was about 4 hours [5].

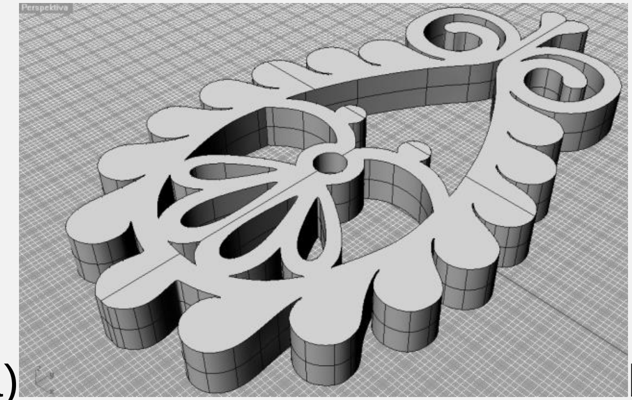
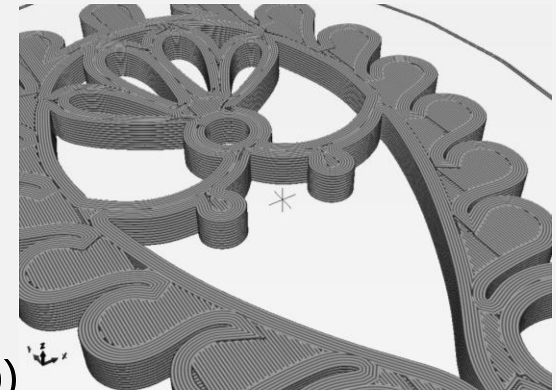
a)

b)

c)


Figure 12. From design to printing of earrings (material Timberfill) – a) design in Rhinoceros, b) slicing, c) printing of final layer

Figure 13. Final model collection – earrings and ring from filament Timberfill

Source: Semanová A.: *The effect of tradition folk culture for clothing creation* (*Vplyv tradičnej ľudovej kultúry na odevnú tvorbu)*, Bachelor work, supervisor: Krmelová V., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2017, in Slovak.

Next sample is propeller of model (Figure 14) of watermill from ABS. The model consist only five layers in the narrowest place of propeller and heated bed temperature had to be suitably chosen to avoid deformation of the edges of propeller during printing.

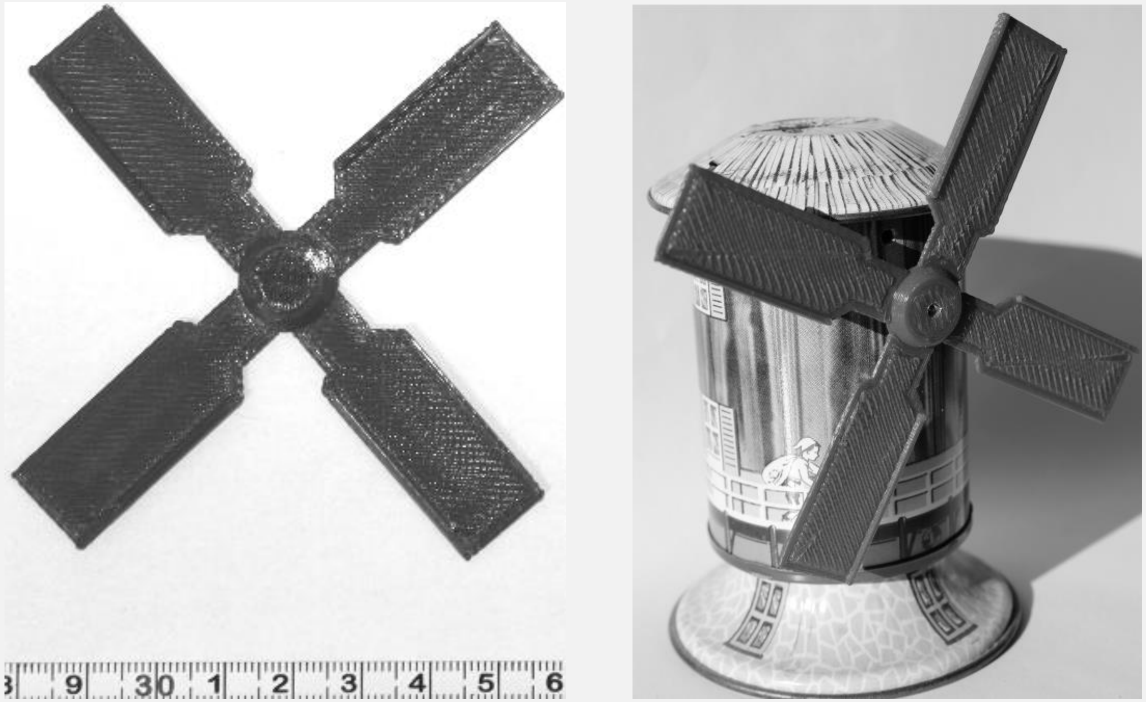


Figure 14. Propeller of model of watermill from ABS (with tape measure in cm) with its use for kid stuff money-box (right)

Miniature of specific tire model (see Figure 15) have also been printed from PLA for purpose as a teaching aid in selected technically subjects, which are oriented with oriented to composite objects and will also be used to plan experiments on static tire test equipment within the Slovak grant project No. KEGA 005TnUAD-4/2016.

a) b) c)

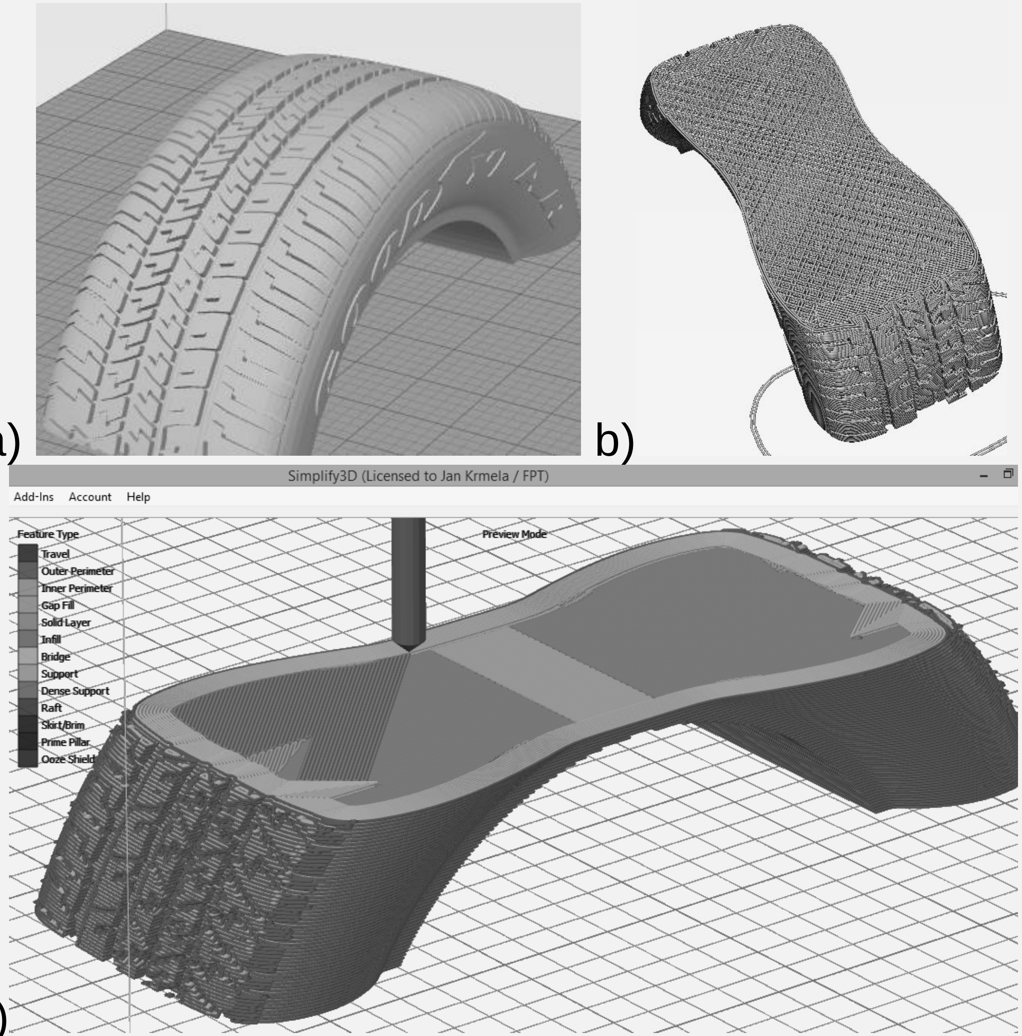


Figure 15. Miniature of specific tire model from PLA – a) design 3D geometry model (was downloaded from internet), b) slicing model by Repetier-host, c) slicing model by Simplify3D

By control programs the printing of some parts altogether but sequentially is possible. As sample the two same profiles on the Figure 16. As a first step, the entire one profile was printed, and as the second step after whole first profile printed the second profile was printed. Printing takes place as a single G-code file, but printing of the profiles takes place sequentially. The profiles have high of 200 mm. The G-code was optimized for obtaining of short print time and good quality. The dimensional accuracy of the final object is ± 0.1 mm. The print time of these profiles was approx. 12 hours.

The other big profiles had high of 300 mm, almost the whole height of build platform is used. Sometimes the print time was over 50 hours per one profile only. 3D printing can sometimes be labeled as not quickly production but production requiring longer production times.

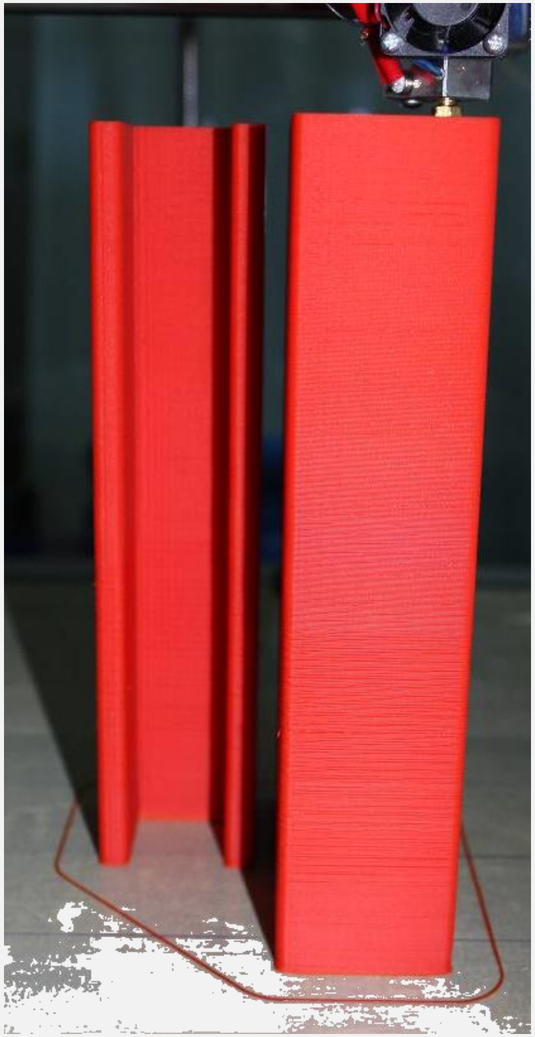


Figure 16. Profiles from PLA – printing of both parts altogether and sequentially

Conclussion

If the heated bed temperature sets on 100 °C for ABS, this temperature would be for ABS on that printer, as the actual measurement would be only 92 °C.

The nozzles have high temperature. There is a risk of burns during the exchange of the filament. Similarly, heated bed temperature 120 °C may be used.

Ensure increased safety during 3D printing. There is a risk of injury by moving parts, on which extruders are of 3D printer. There is a risk of burning with a hot nozzle, for example, when changing the filament and adjusting the pad.

In the future we plan printing with two materials simultaneously for purpose creating composites not only for educational process.

The optimum print settings (especially print speed, layer thickness, temperature) are needed to search to avoid defects and print errors.

Further, the 3D printing of two materials is contemplated in order to produce a part of the composite incorporating, for example, filament Carbon20.

The project was funded by the Cultural and Educational Grant Agency of the Slovak Republic (KEGA), grant No. ***KEGA 002TnUAD-4/2019****.*

1. LCD Controller Menu, German Reprap [online]. Available on: https://www.germanreprap.com/wp-content/uploads/2016/10/firmware_-_lcd_controller_menu-1-1.pdf
2. X400 PRO 3D printer, German Reprap [online]. Available on: https://www.germanreprap.com/en/products/3d-printer/x400-pro-3d-printer/ and https://www.germanreprap.com/wp-content/uploads/2016/10/x400ce_3d_printer_manual-1.pdf
3. Slic3r User Manual, German Reprap [online]. Available on: https://www.germanreprap.com/wp-content/uploads/ 2016/ 10/slic3r_user_manual-1.pdf
4. Pajtáš M.: *3D printing for technical applications and design software extension for the PRINTER GERMAN RepRap X400 (3D tlač pre technické aplikácie a návrhy softwarového rozšírenia pre tlačiareň German RepRap X400)*, Bachelor work, supervisor: Krmela J., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2016, 62 p., in Slovak.
5. Semanová A.: *The effect of tradition folk culture for clothing creation (Vplyv tradičnej ľudovej kultúry na odevnú tvorbu)*, Bachelor work, supervisor: Krmelová V., Púchov: Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, 2017, in Slovak.

TIRE SAFETY

INTRODUCTION

The tire tread contributes to a good road grip and water expulsion, the multi-ply steel belt optimizes the directional stability and rolling resistance, the steel casing substantially determines the driving comfort, the inner-liner makes the tire airtight, the sidewall protects from lateral scuffing and the effects of the weather, the bead core ensures the tire sits firmly on the rim, and bead reinforcement promotes directional stability and a precise steering response.

The high security and long life of a tire can be assured only by its correct assignment to the particular type of vehicle and automobile as show Figure 1 (tires only for road operation, for off-road, combined operation as well as for summer or winter conditions). Tires are divided by type of tire-casing on radial, diagonal, bias-belted and special tire.

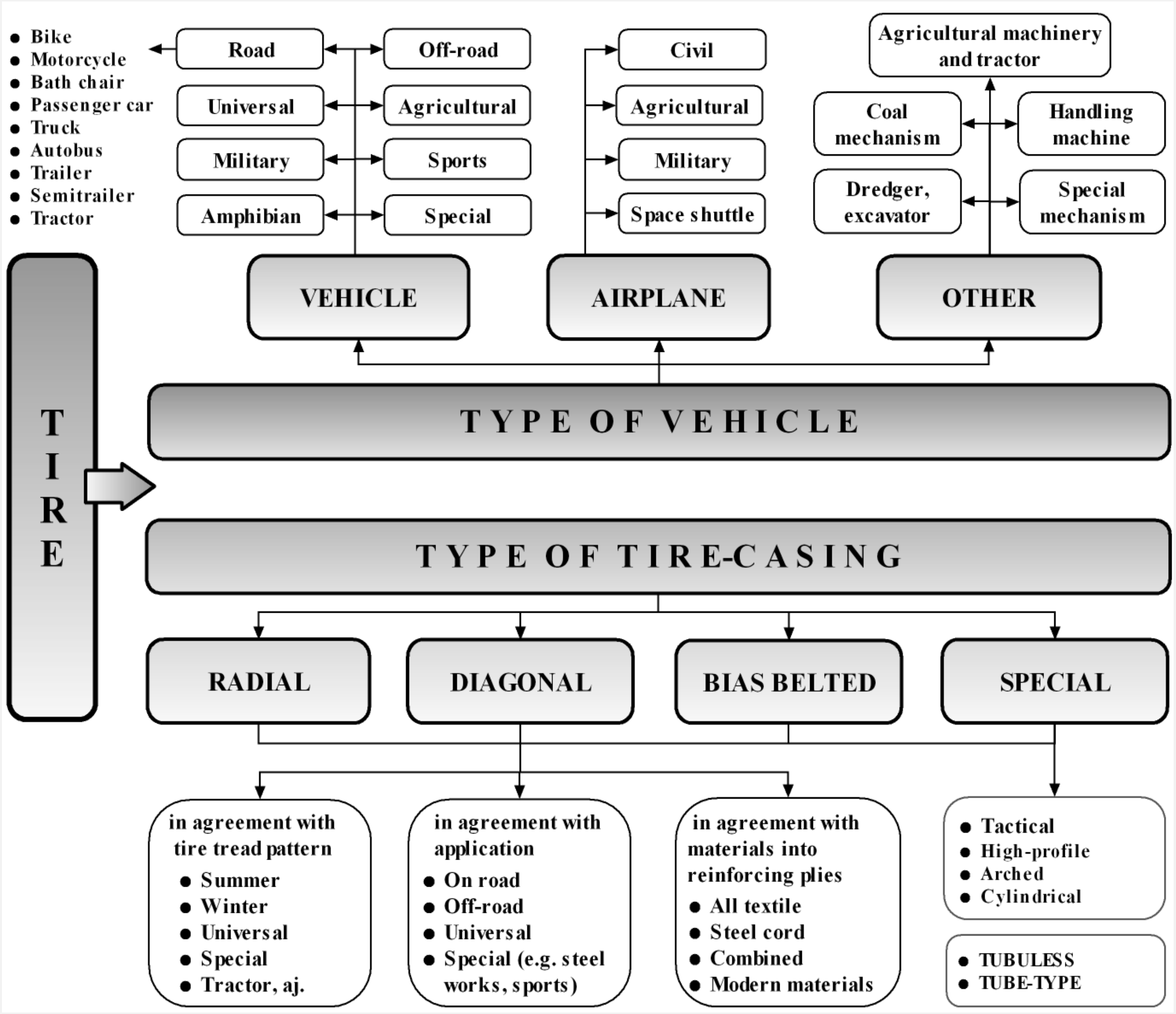


Figure 1. Type of tire by vehicle and construction

Radial tires can be considered as pressure vessels with a maximum pressure given by the particular type of tire. A tire can be generally considered as a statically and dynamically loaded automobile element. The structured view of a tire is apparent from the Figure 2.

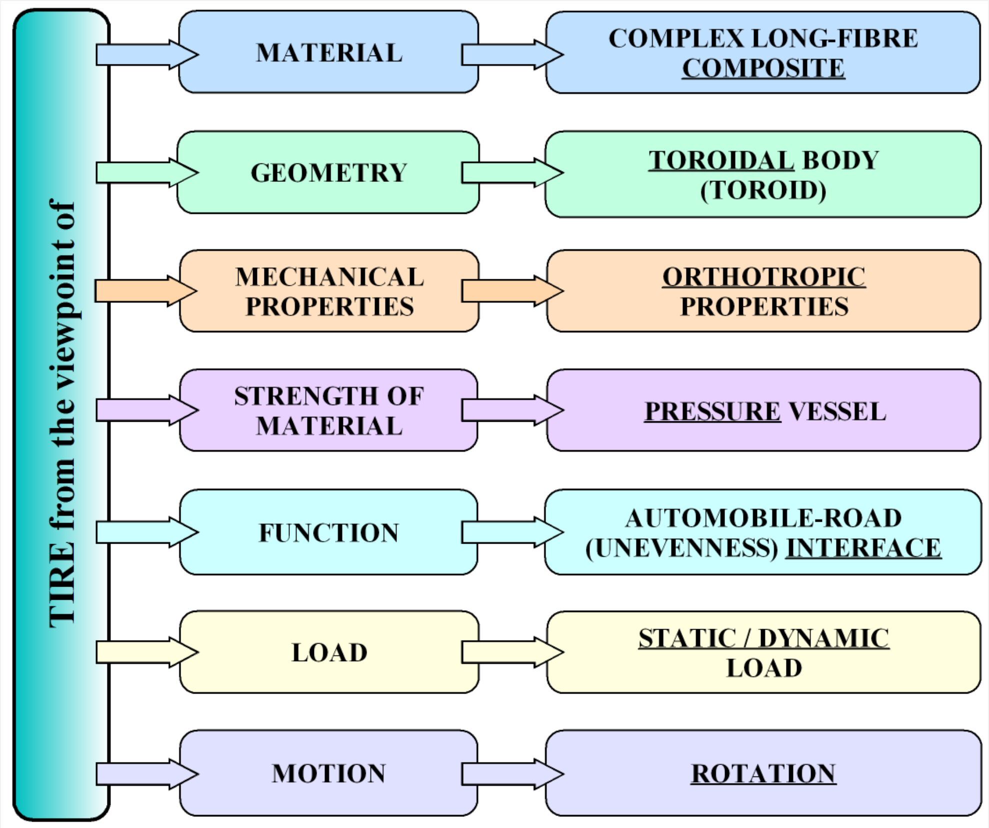


Figure 2. Definition of tire from various viewpoints

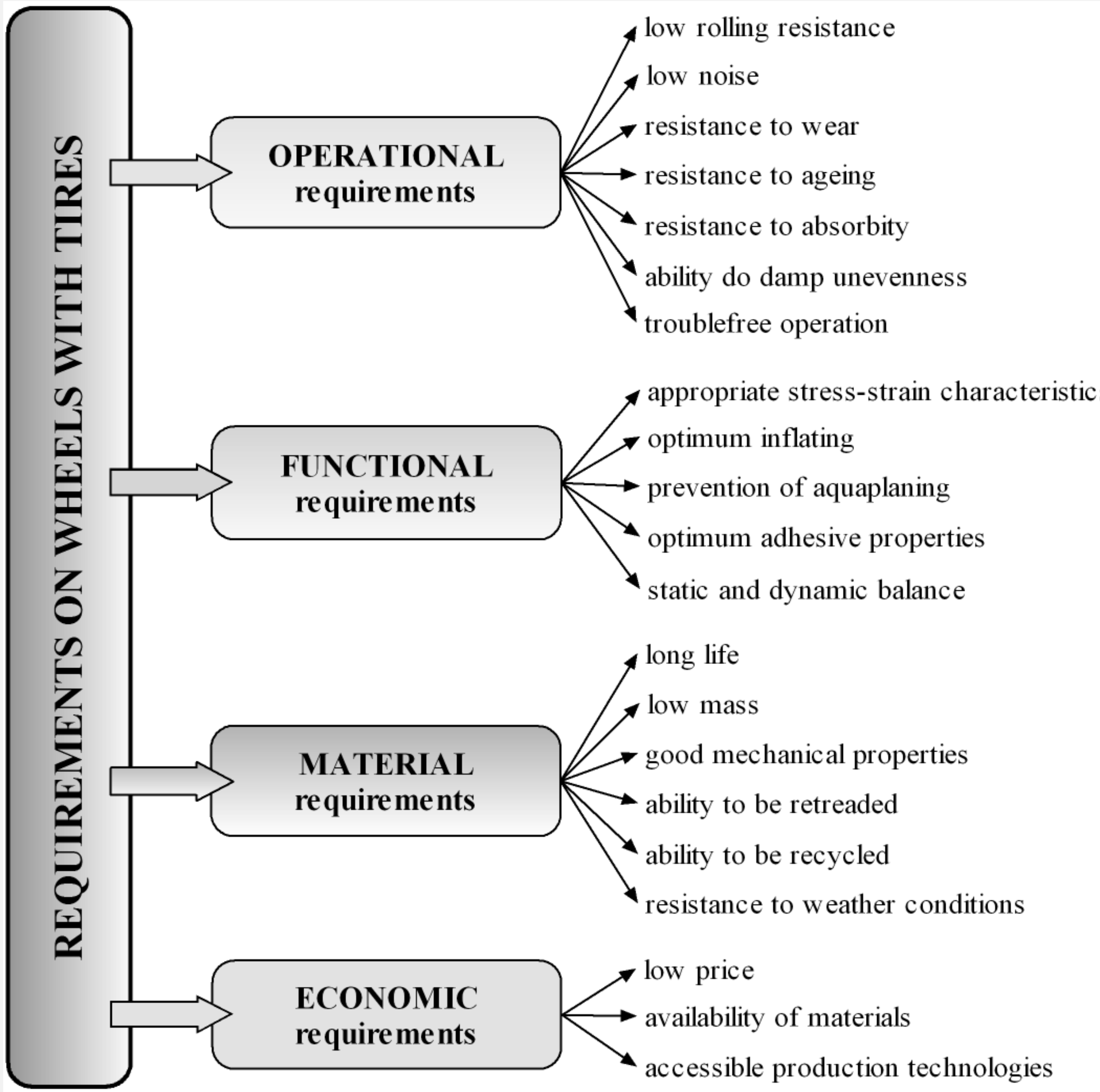


Figure 3. Basic requirements of wheels with tires

The function of wheels with tires is not only to align a car reliably. As can be seen in more detail from the Figure 3 there are more requirements on tires. The main operating requirements on car tires are that car wheels should be as light as possible and at the same time tough, statically and dynamically balanced.

The main requirements on tires are, apart from other things, high wear resistance, optimal deformation characteristics, low rolling resistance, high operational life and safeness, etc. Wheels with tires must meet particular functional requirements given by parameters of tires which affect the running properties of the car, i.e. affect their dynamic behavior (car maneuverability, stability, acceleration, deceleration, driving comfort, etc.).

Tire safety is passive and active - see Figure 4. Passive safety depends on the quality of the production of a tire casing, the applied technology and used materials and in the case of computational modeling also on the accuracy of the performed calculations and appropriate choice of the computing algorithm.

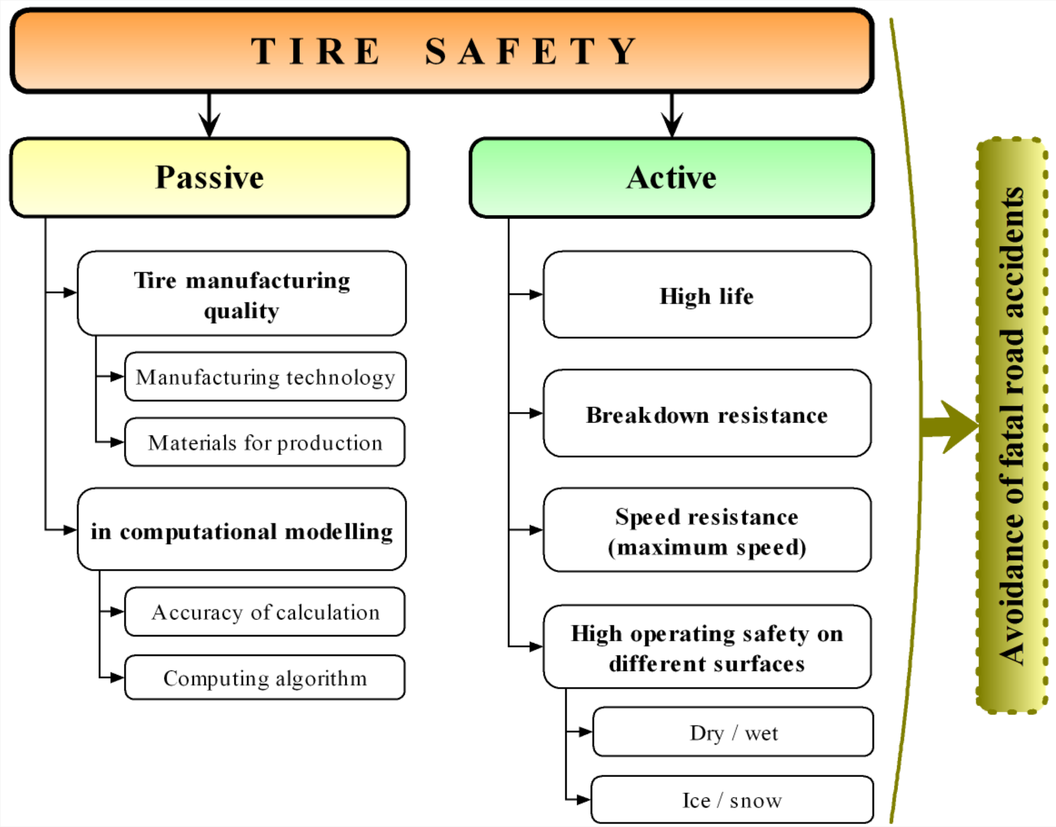


Figure 4. Viewpoints of tire safety

Requirements on active safeness are particularly high running safety on various types of road surfaces, breakdown resistance, speed resistance and high life of materials used for the production of tires, namely reinforcing materials.

Tire life is affected by many factors (e.g. manufacturing way of a tire, its operation and handling, storage conditions of base materials for tire production etc.) while it's assumed an ideal adhesive bond among the rubber elements in matrix (e.g. an interface between tire tread and textile overlap belt) and the cord reinforcing and rubber drift inside tire carcass, and belts is assumed in this cases. For long life tires must resist during operating to surrounding effects, to negative effects of operation and to other effects, which could lead to wear and degradation processes as are e.g. delaminations.

The aim is to avoid fatal road accidents which might be caused by tire casing defects either by neglecting operating conditions of tires (depth of tire tread pattern, tire inflation pressure, use of inappropriate tires with a different structure, etc.) or by bad vulcanization during the manufacturing process creating delaminations.

The tire is during the operation exposed to combined loading as from a mechanical (statical, dynamic) as a temperature point of view (local heating in subzones, overall heating in the tire-tread area permeating into the tire during breaking). Also this has to be considered in defining tire safety at high speeds.

The breaker angle (see below) also influences the security of a tire as well as the driving comfort and stiffness of a tire. The driving properties of the tire as a whole could be substantially improved by optimizing such angle of steel wires of the breaker.

THE TIRE DESCRIPTION

The work of the authors over a long period of time is devoted to radial tires. The automobile radial tire consists (e.g. cross-sections of selected tire 165 R13 Matador are on the figures 5 and 6, in detail on the Figures 6 below and 7) of rubber parts and composite structure parts (Figure 8) with textile cords (especially PA 6.6 and PES textile fibers are used) and steel-cords into tire tread as reinforcements.

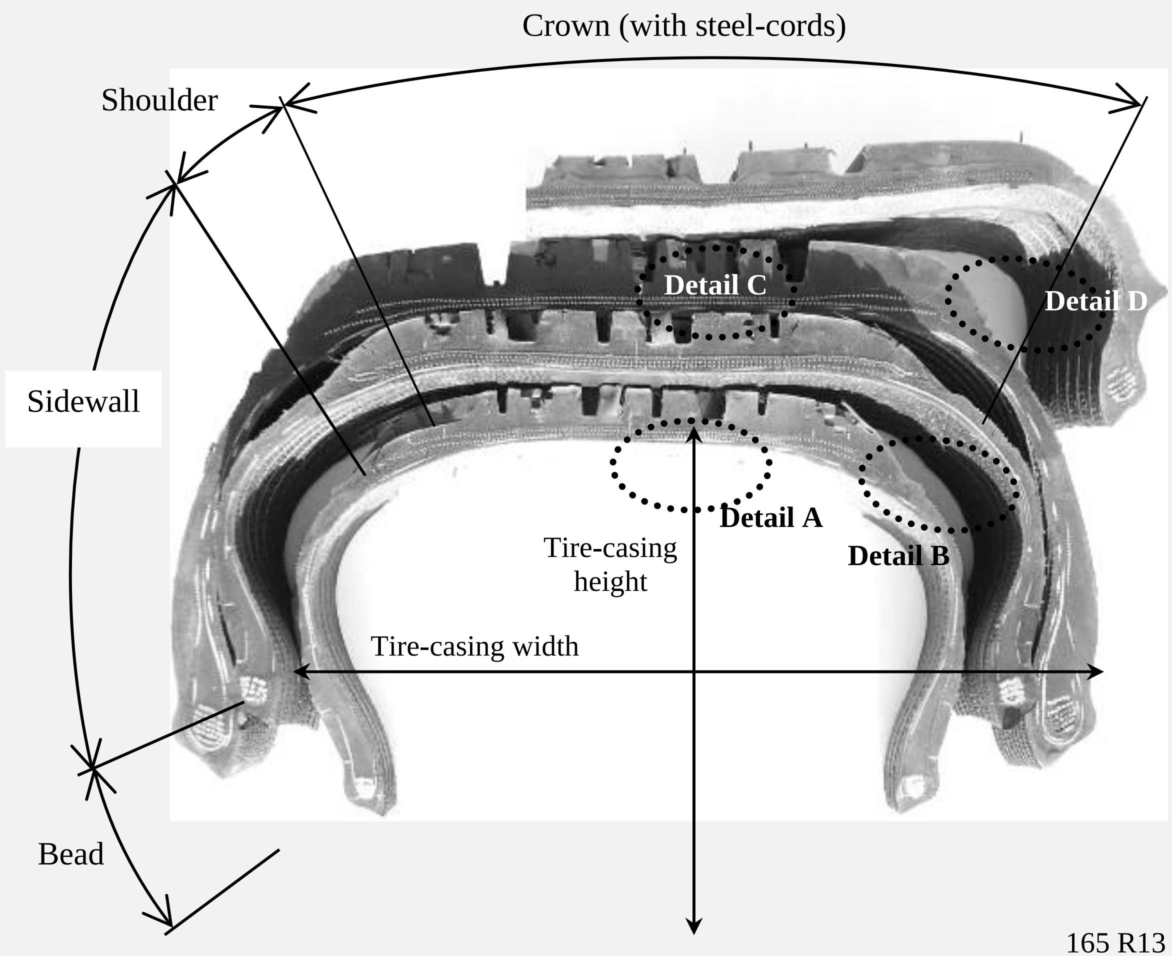


Figure 5. Cross sections of tire-casing

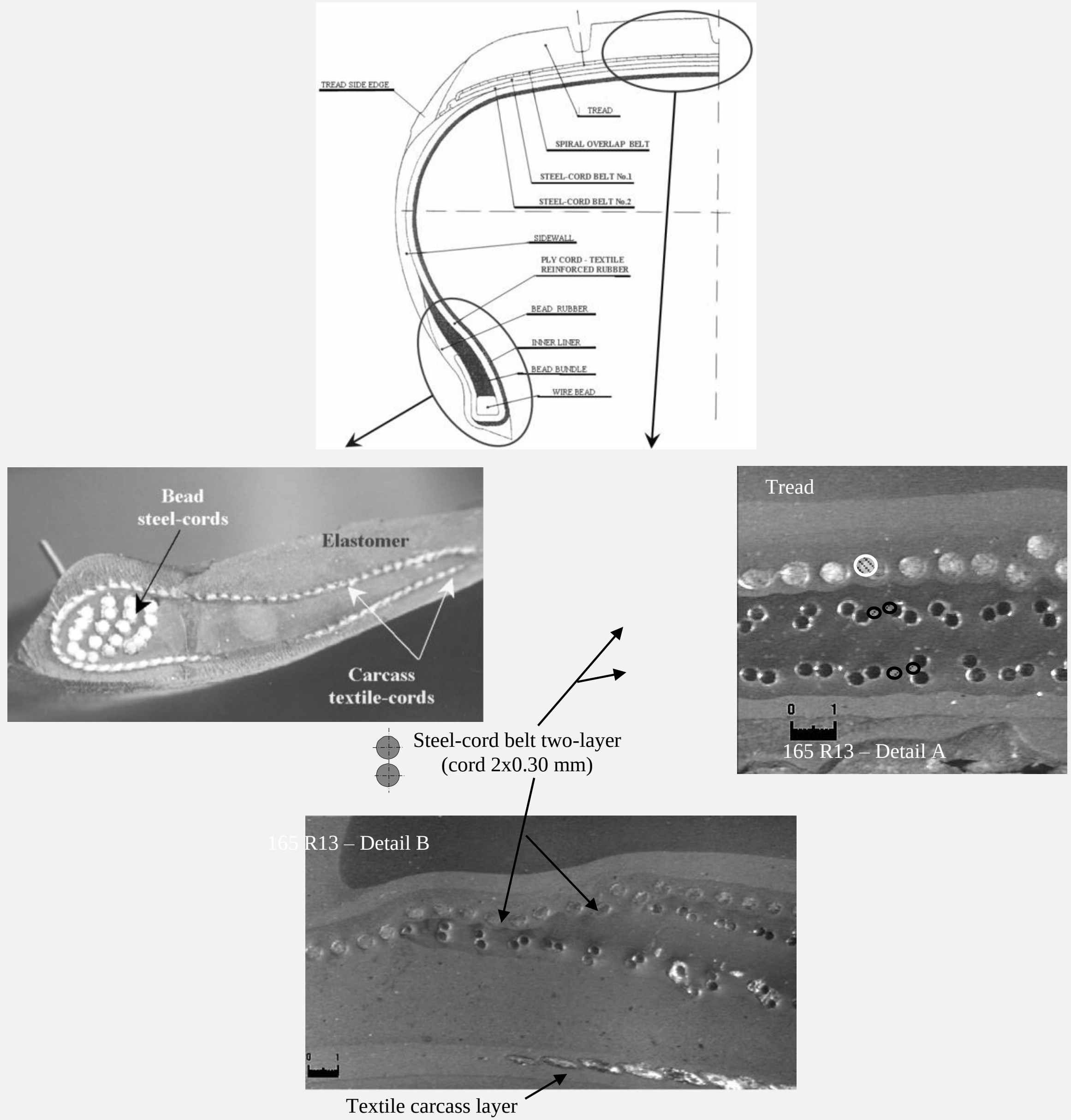


Figure 6. Structure of the tire 165 R 13 [based on Matador] with microstructure of reinforcing plies detail A in the area of tire crown and detail B at the end of steel-cord belt (below)

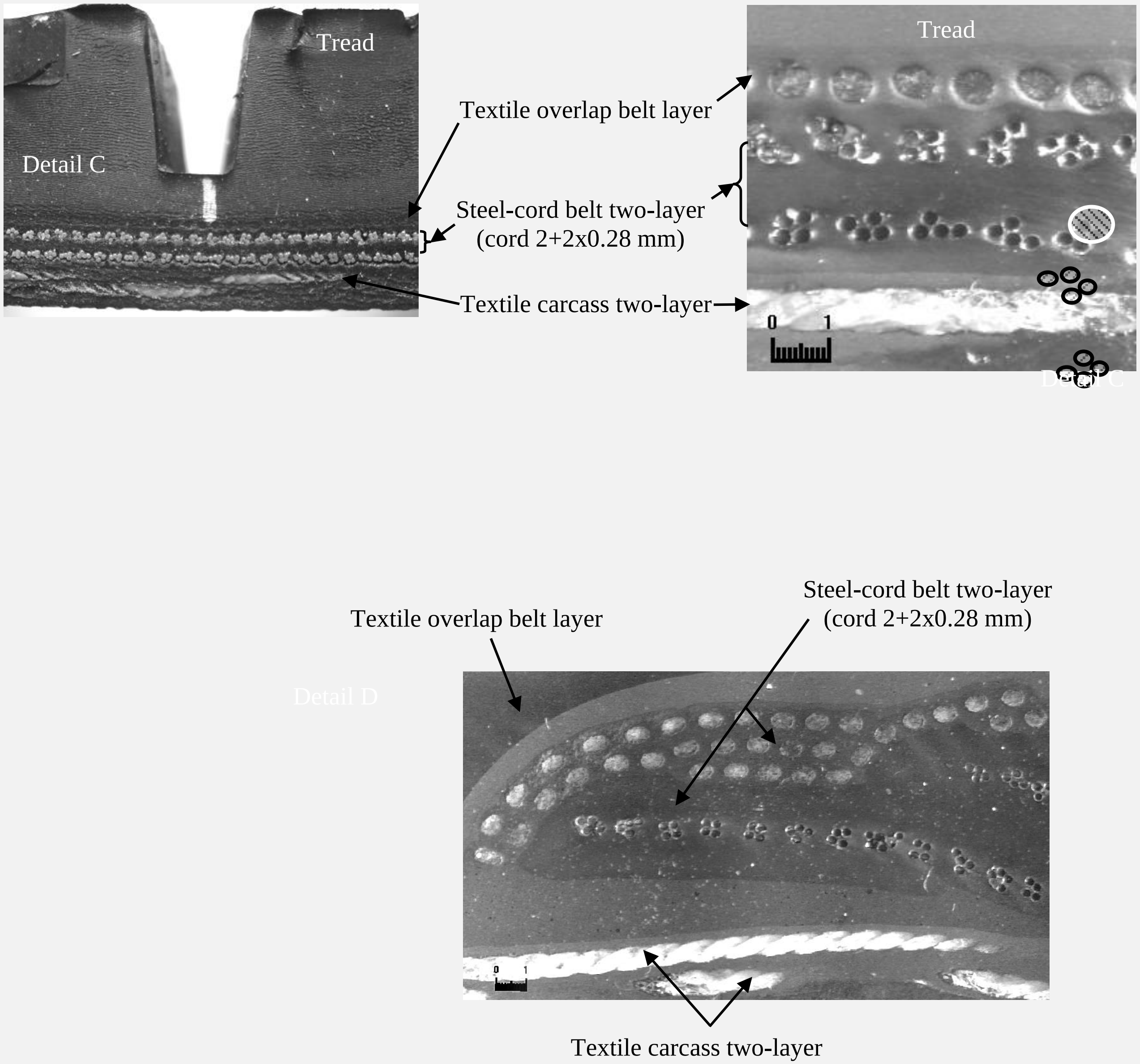


Figure. 7 Detail C in the middle of tire crown and detail D at the end of the belt layers (below) of different radial tire

The composite structure parts applied into radial tires (Figure 8) are:

- Textile tire carcass;
- Textile overlap belt;
- Steel-cord belt.

These structures of tire have got:

- Different cord-angle (e.g. for steel belt applied angle 21-27° into radial tire for passenger car);
- Material of cords (steel, textile, Kevlar, combine);
- Shape and construction of cord (wire, wire strand);
- Numbers of layer (single-layer or multi-layer).

So a tire has got characteristic specific deformation properties.

One construction of tire is used for passenger cars, other constructions for trucks, off-highway cars and sports cars. The tires for air transportation, agricultural vehicle, mining machine and other vehicles have got complicated structured in comparison radial tires for passenger cars. The tire structures are differentiated by numbers of reinforcing plies into belt tire, construction of belts, materials and cord-angles, geometry parameters of tire, width of belts etc. These aspects are influenced on final behavior of tires, namely deformation characteristics of tires. It is possible increase of resistance of tire to some degradation processes by suitable tire construction.

Two-layer steel-cord belt is used in radial tire *165 R13 Matador* with construction of cord *2x0.30 mm* with texture *961* (number of cord over meter width of belt). The cord angle is ± *23°*, the layers are symmetrical.

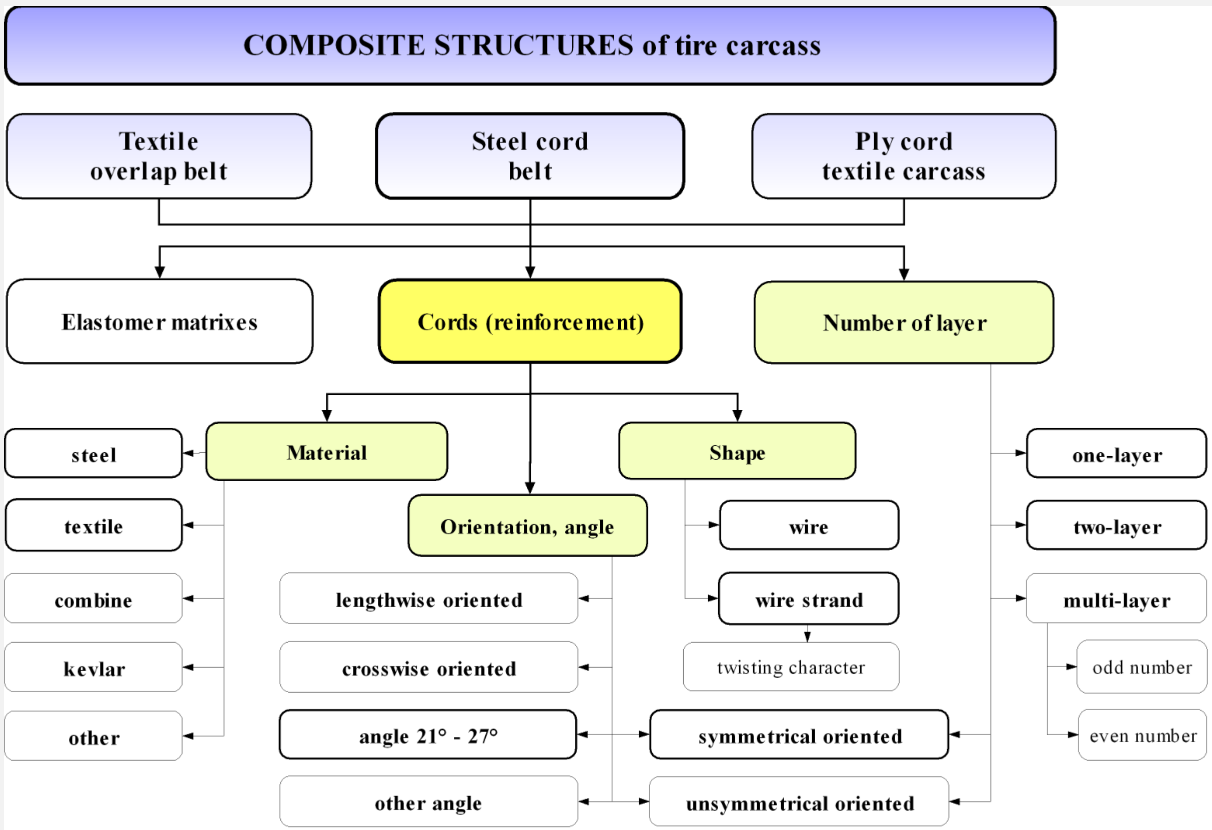


Figure 8. Composite structures used in tire

Structure – cord orientations of radial tire *22.5"* for truck vehicles presented in the Figure 9 as an example.

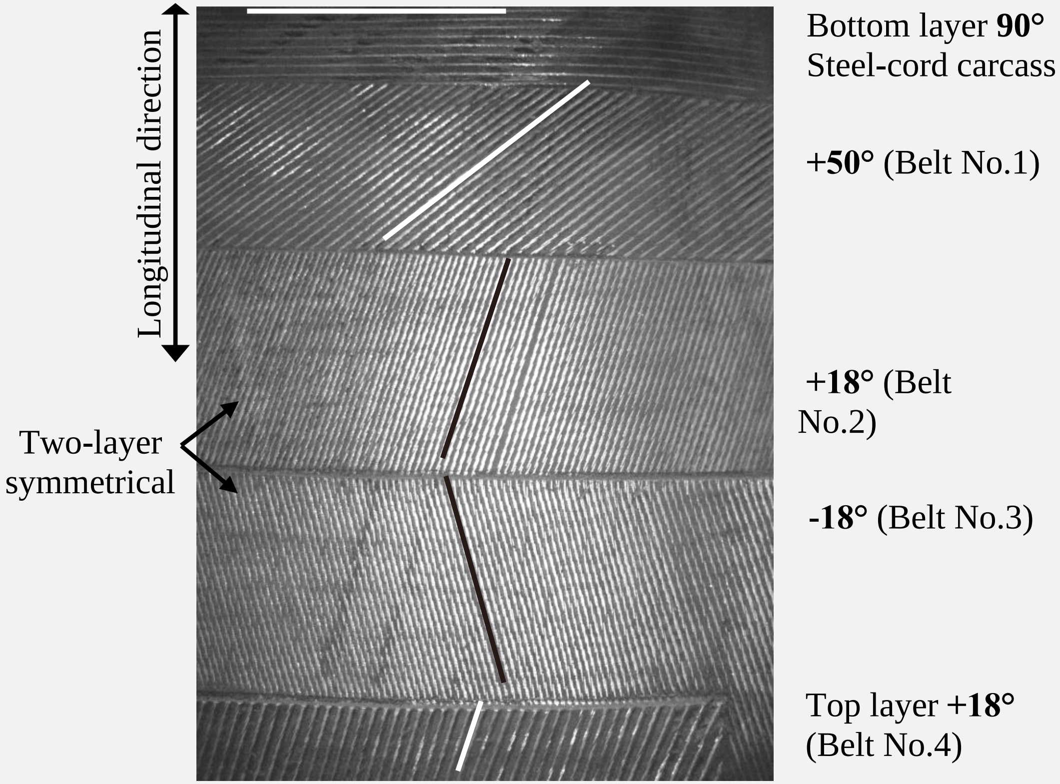


Figure 9. Structure of truck tire in the middle of tire crown

Steel-cords can be in form of thin wire or wire strand with different constructions. High-strength steels are used exclusively for steel-cord production and good adhesive bond between rubber and cords required. Steel-cord surfaces are modified by chemical-thermal treatment (braze or copperier, Figure 10) to achieve the best adhesive bond of a steel cord and rubber and get it corrosion resistant. The substantial factor, which expressive influence on coherence of whole tire, is good adhesive bonds between reinforcement materials and rubber parts of tire.

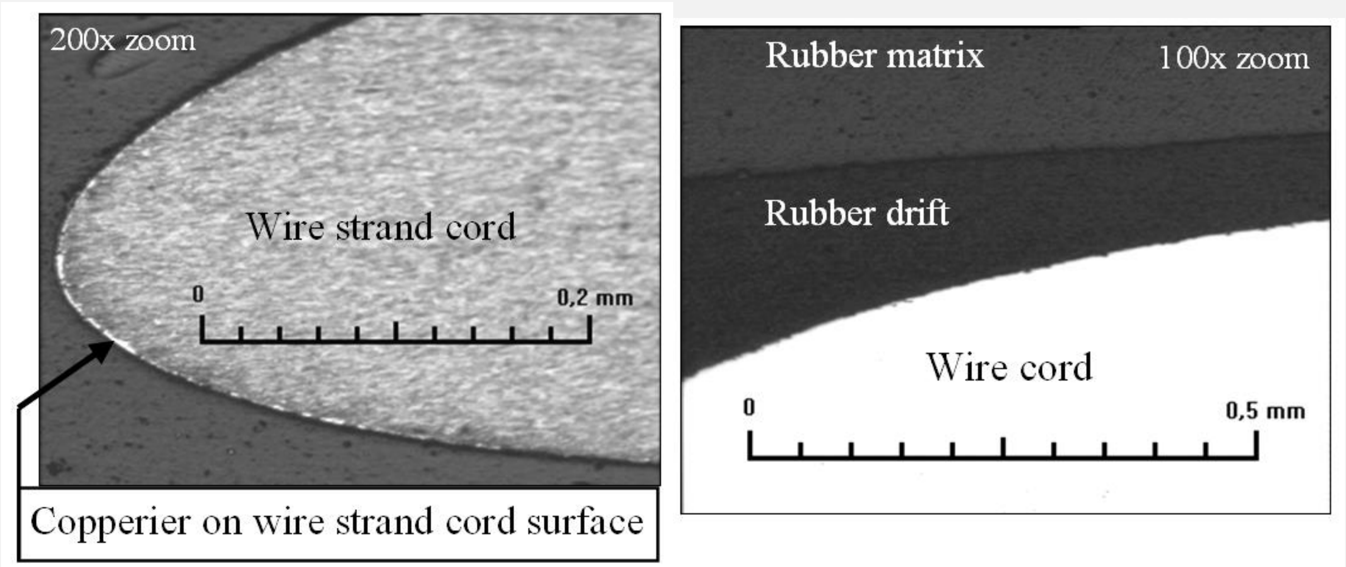


Figure 10. Steel-cord surface and interface between cord-rubber drift-rubber matrix

The tire steel-cords are exposed to various chemical and thermal influences (Figure 11) during cyclic loading states by tensile-compression in tire loading processes. Account on this the adhesive bond is more exposed to be damaged than the basic materials (steel, textile and rubber). The aggressive environment (e.g. action of salts in winter) activates the corroding process on steel-cord surfaces that can lead to decreasing of the adhesion between reinforcement-and-matrix, which demonstrates it self by negative changes in material properties of steel-cord belts and such of whole tire too.

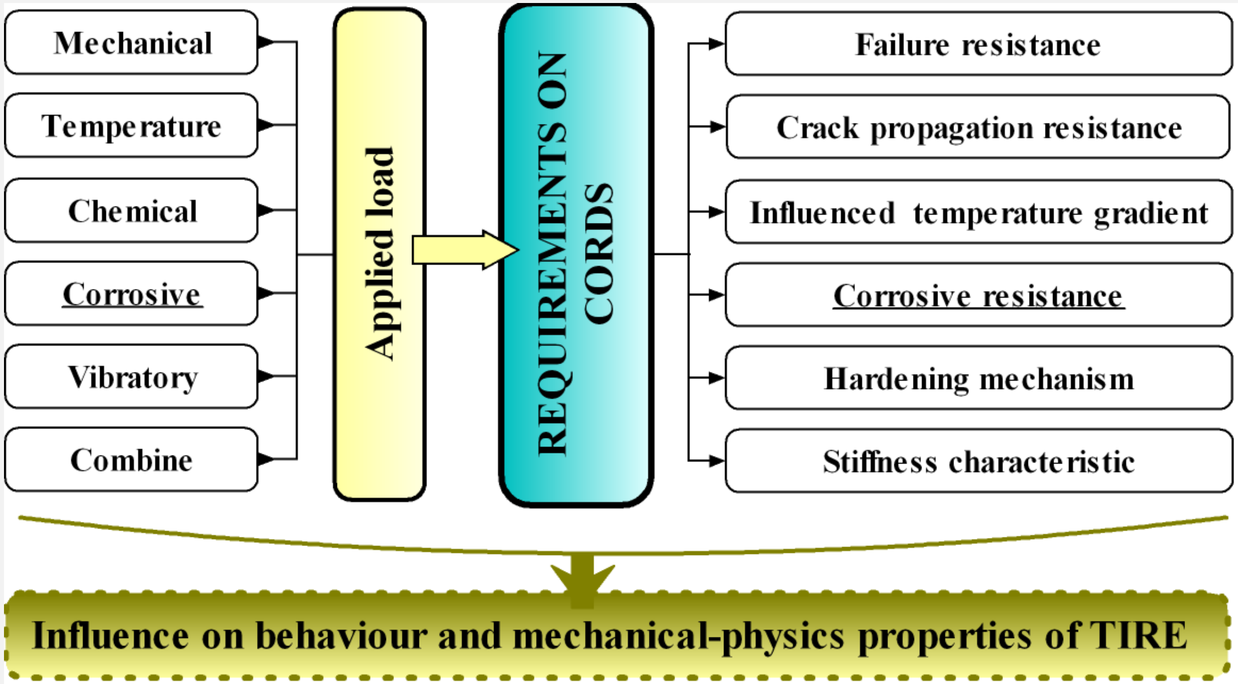


Figure 11. Requirements on reinforcing tire cords

In addition if the tire is in use is defected in tire crown (e.g. defect caused by sharp object as a nail and after the repair is placed back into operation) the initiation of corrosion with faster process is being assumed. Consequently this can lead to gradual or sudden failure of the steel-cords and bonds of steel-cord and rubber with a serious car accident as a final consequence.

Any damage in the area of tire crown, namely into steel-cord belt, is perilous.

DEGRADATION PROCESSES OF TIRES

Tires are subject to internal and external effects which can more or less cause limit states leading to degradation processes Figure 12. Ones of them marked as very dangerous and unacceptable tire casing damage are so-called separations and delaminations (Figure 13 left).

Breakdown or damage is not necessary only at the border of single layer e.g. between the layers of steel-cord belt plies in the tread of tire casing, but also between rubber matrix and reinforcing cords. Delamination between rubber drift-rubber matrix on Figure 13 right.

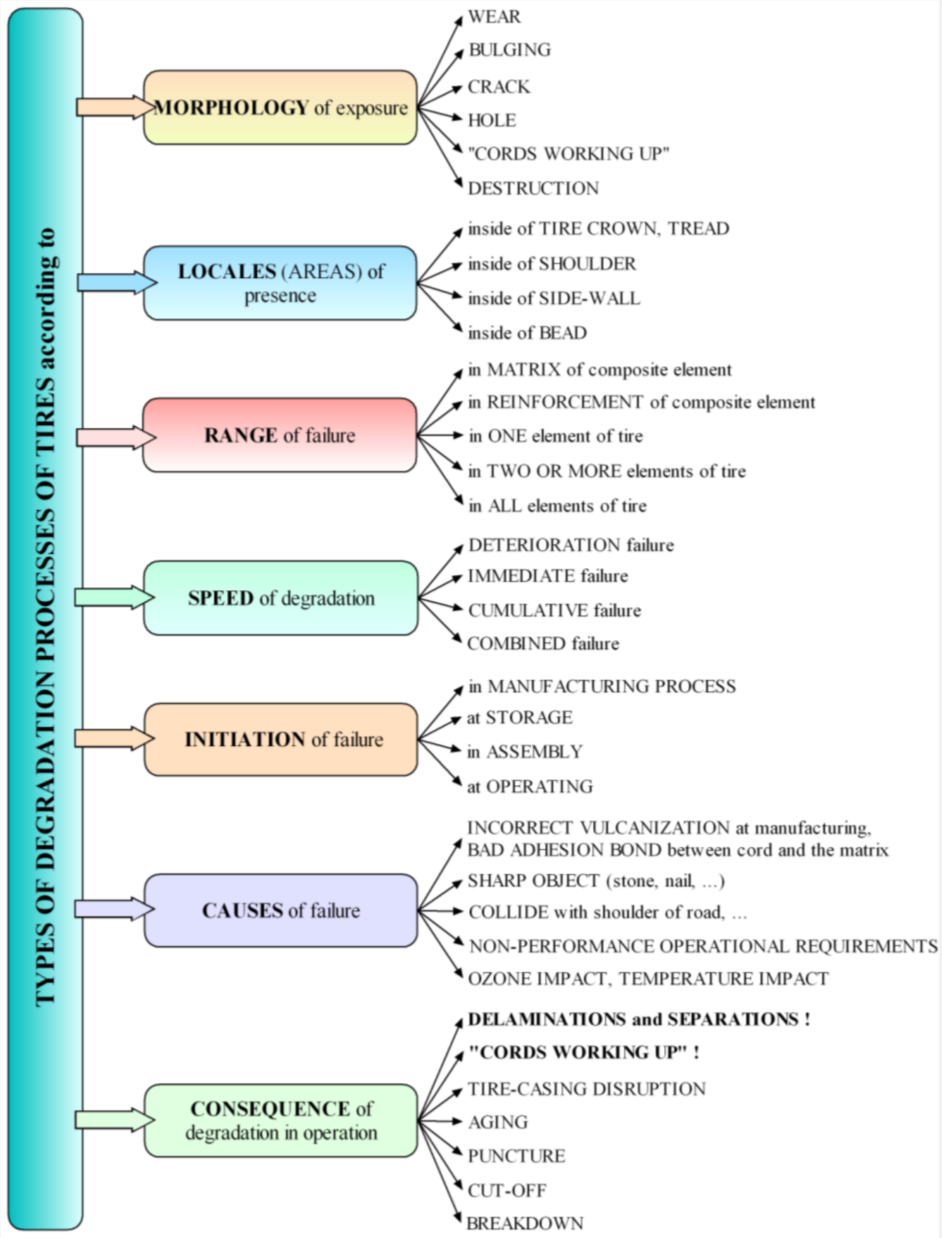


Figure 12. Degradation processes of tire

Root cause of mentioned degradation processes can be caused by using of low quality materials for the tire in manufacturing process, their incorrect storage leading to early aging especially at rubber compositions, not keeping optimal manufacturing conditions – vulcanization, as well as by the influence of incorrectly pressurized tire and damaged adhesive bond between cords-matrix and belt plies etc. Damaged adhesive bond is greatly decreasing of tire safety during the operation of a vehicle at high speeds. This has a significant influence to the quality of the tire casing expressing by lowering the level of usage (decreasing speed index) or leading to the catastrophic situations. In every case it is mandatory to avoid these premature limiting states.

In tires can be caused:

- Cords release leading to the cords working-up;
- Separations – delaminations;
- Combined wear;
- Total breakdown.

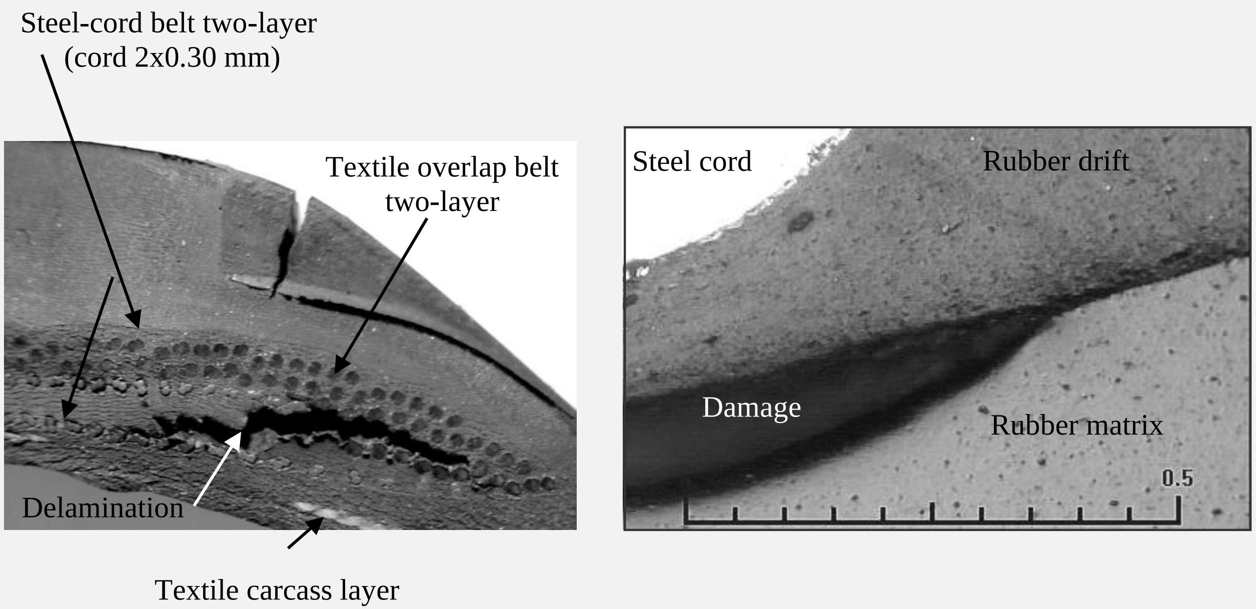


Figure 13. Factitious delamination between belt plies and damage between rubber drift-rubber matrix (right)

Results of wear due to adverse change (Figure 14) of tire casing surfaces are gave in impairment of mechanical-physics properties of whole tire.

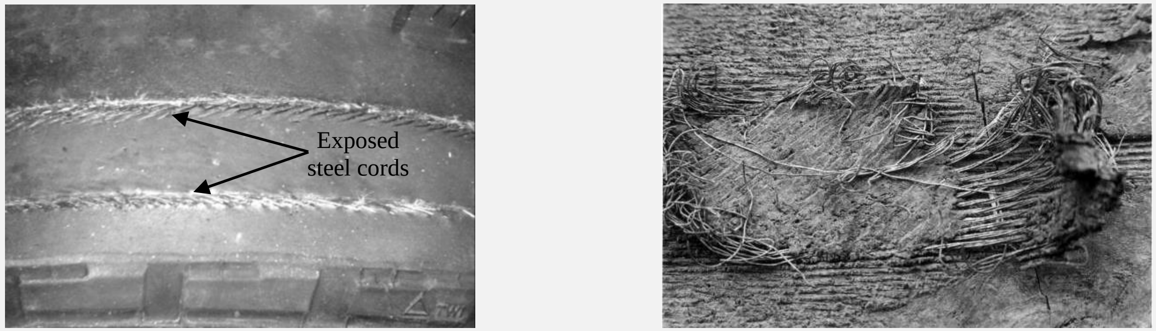
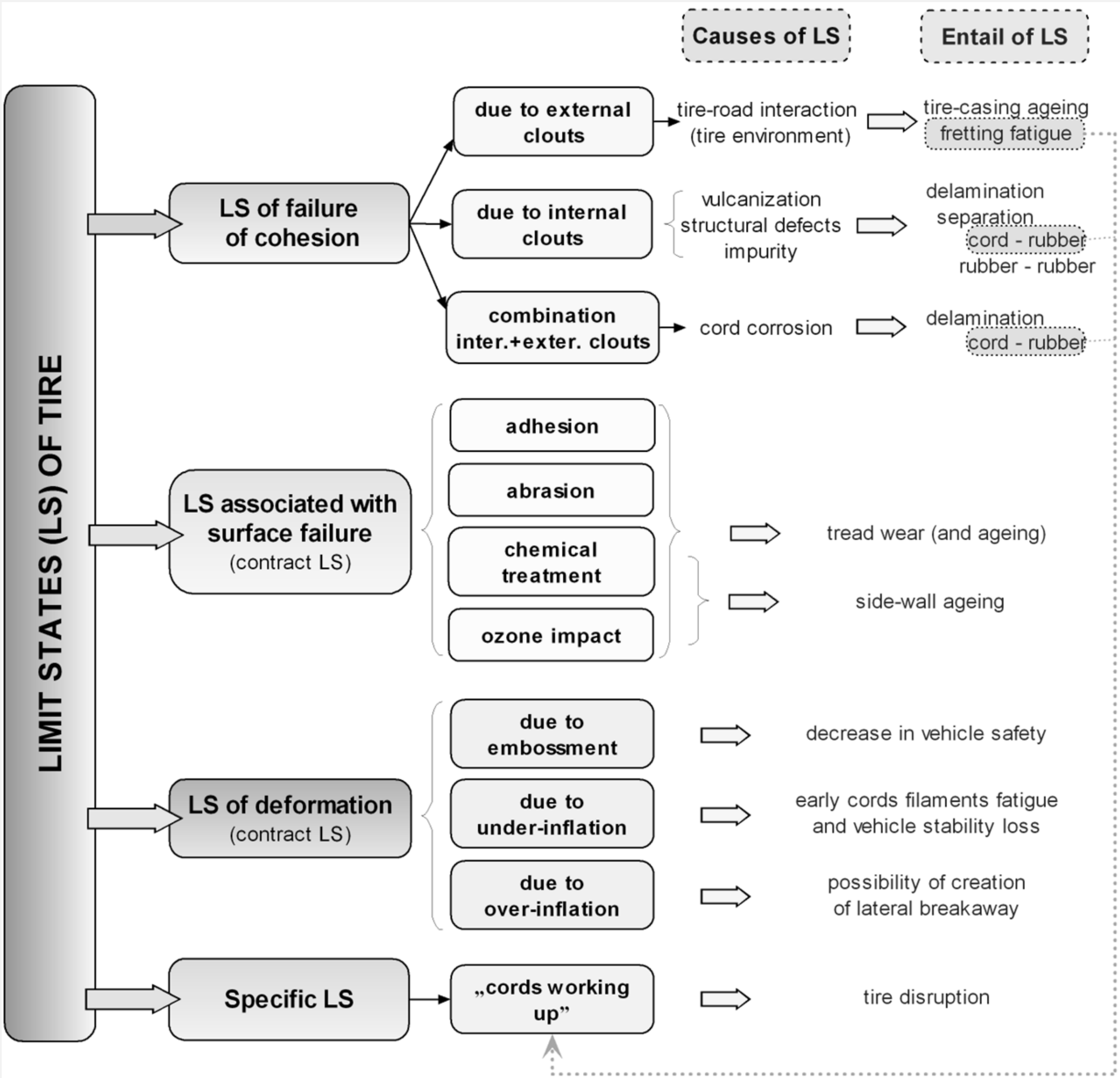


Figure 14. Extreme wear of tire on tread surface; and “cords working-up” (right-photo by Prof. Janíček, VÚT Brno, Czech Republic)

This will be influenced the incoming behavior of tire in operation and related interfaces between of tire and surroundings. Particularly dangerous is creation of failure in such places where initiation is not assumed to be caused by impairment of the surface. Structural changes in a part of tire as composites are not only responsible for the impairment of its properties but also of its geometry which can initiate vibrations leading to loss of the part’s functional ability of whole vehicles (automobiles).

Wear can be of various character (development, place, form, appearance) and leads to the failure of the tire (Figure 15). The task of prediction is to find ways how to reduce wear and to postpone initiation of dangerous degradation processes such as delamination and separation and to focus on the removal of initiators of these degradation processes.


Causes of LS
Entail of LS
LIMIT STATES (LS) OF TIRE
LS of failure of cohesion
due to external clouts
tire-road interaction (tire environment)
tire-casing ageing
fretting fatigue
due to internal clouts
vulcanization
structural defects
impurity
delamination
separation
cord - rubber
rubber - rubber
combination inter.+exter. clouts
cord corrosion
delamination
cord - rubber
LS associated with surface failure (contract LS)
adhesion
abrasion
chemical treatment
ozone impact
tread wear (and ageing)
side-wall ageing
LS of deformation (contract LS)
due to embossment
decrease in vehicle safety
due to under-inflation
early cords filaments fatigue and vehicle stability loss
due to over-inflation
possibility of creation of lateral breakaway
Specific LS
„cords working up"
tire disruption

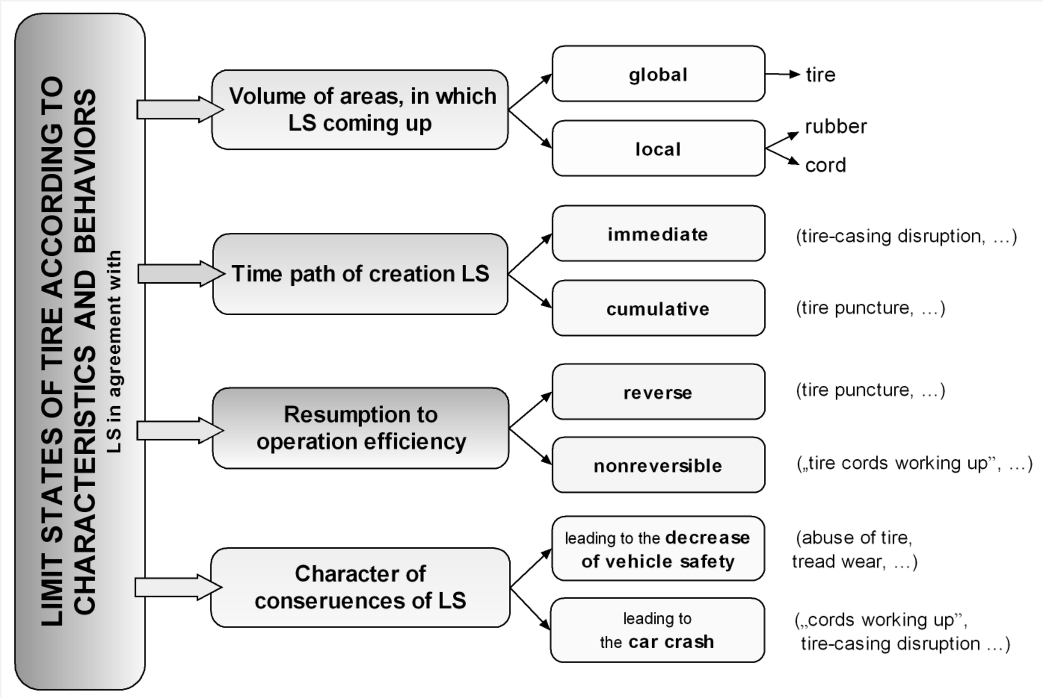


Figure 15. Limit states of tire

Wear due to adverse changes of surfaces results in impairment of properties and behavior of parts. Particularly dangerous is failure in such places where initiation is not assumed to be caused by impairment of the surface. Structural changes in a part are not only responsible for the impairment of its mechanical properties but also of its geometry which can initiate vibrations leading to loss of the part's functional ability. All this resulted in environmental and economical losses.

Tires must resist during operating to surrounding effects, to negative effects of operation and to other effects, which could lead to wear and degradation processes as are e.g. delamination. Resistance to the following effects is considered (Fgure 16):

- Puncture – capability of tires to resist puncture by sharp objects;
- Cut-through – capability of tires (especially of the tread and sidewall) to resist contact with sharp objects;
- Breakdown – capability of tires to resist damage during short-term loading by concentrated forces;
- Fatigue – capability of tires to resist material fatigue and defects in consequence of repeated loading cycles;
- Separation and delamination – capability of structural tire components to maintain integrity of the system during operation;
- Humidity – tire elements must be able to resist degradation by contact with water;
- Ozone influence – capability of tires and of theirs components to resist degradation caused by ozone present in atmosphere;
- Temperature – tire components must be able to resist high and low ambient temperatures and also consequences of contact with the road;
- Chemicals – capability of tires and theirs components to resist degradation caused by chemicals (in winter – influence of salt solutions);
- Corrosion processes – capability of tire reinforcing cords to resist corrosion, etc.

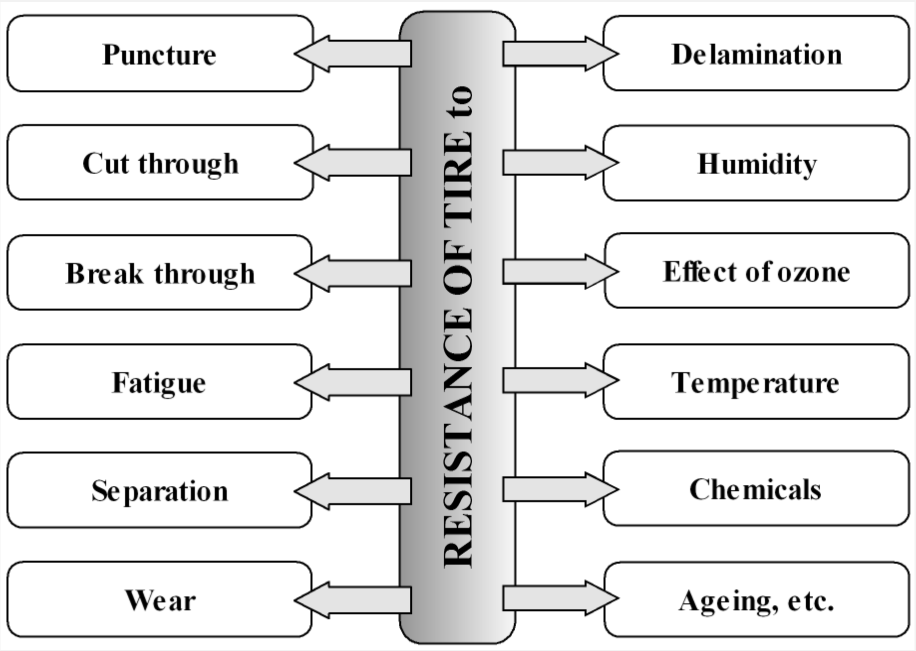


Figure 16. Basic requirements on the tire resistance

An appropriate design will help to increase resistance of the tire to certain degradation processes such as e.g. corrosive attacks initiated by local damage of the tire in cases where damaged are the steel cord reinforcements. Design optimization aimed at resistance to degradation and at achievement of longer life can be well performed by computer modeling. The computer modeling has reached such a level that it can work with a great amount of input data which represent the initiation of degradation effects on such a complicated technical object as a tire.

Safety at work during

DYNAMIC TESTS

OF TIRES

Stiffness is an important parameter in relation to the calculation of tires as the integral car system because the stiffness value replaces the tire including its geometry, structure, material parameters, influence reinforcements and inflation pressure. But static experiments do not have to provide information on operational behavior. The dynamic experiments are needed for obtain of stiffness value of tires. At University Pardubice, the dynamic test machine for high speed tests of tires (call as dynamic adhesor) has rotating steel drum (main part of test machine) with a smooth surface and diameter of 1705 mm.

„DYNAMIC ADHESOR“

Radial loading max 0.5 t

Max. **velocity 180 km/h !**

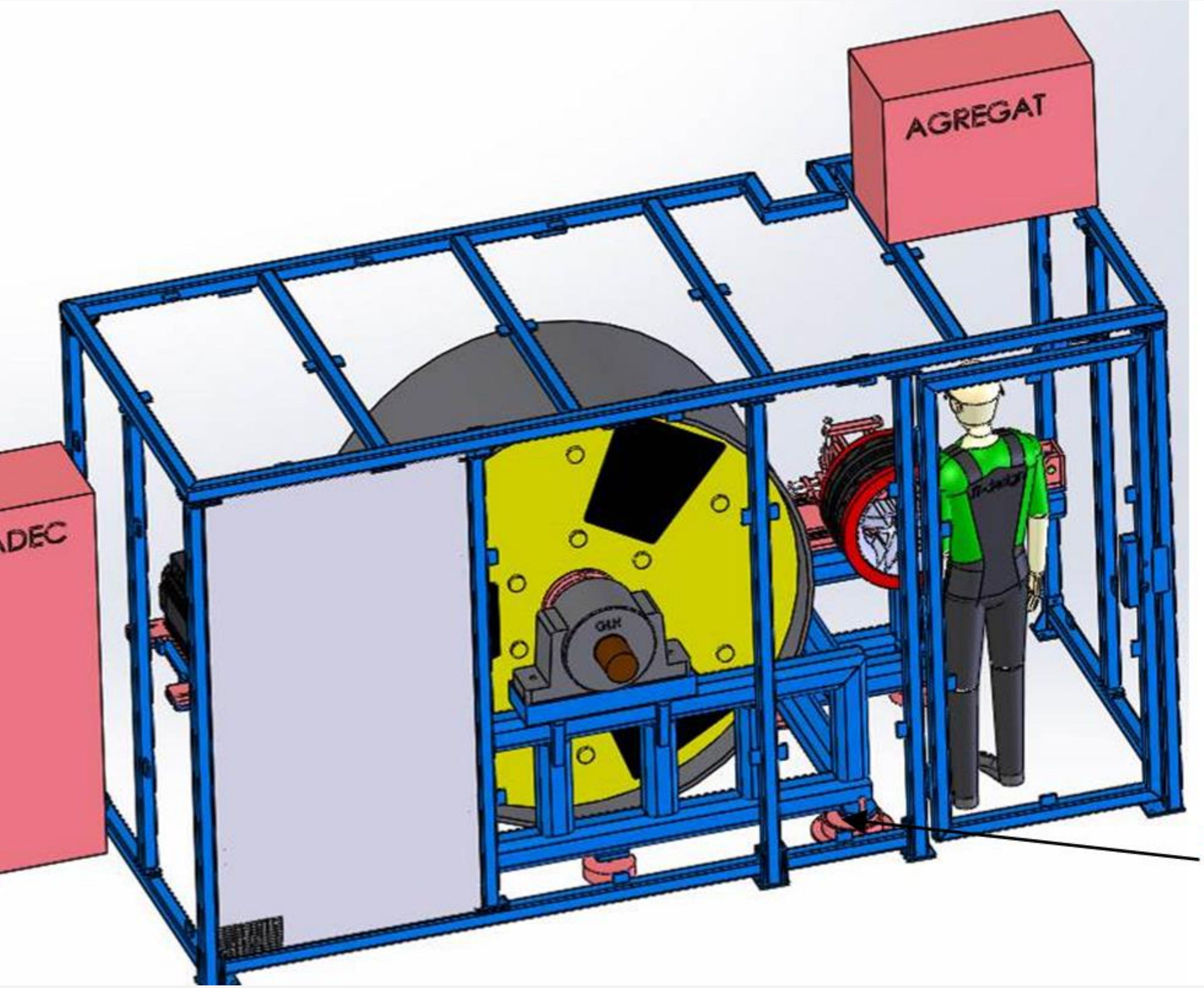
Dynamic test machine with detail of deformation of tire during rotation

The drum is fitted in a supporting frame, which must secure the needed stiffness of the whole test machine. The test machine can simulate the contact between a tire and a road with a specified velocity. The maximum velocity is 180 km/h and radial load of the tires up to the value of 510 kg is possible. It is possible to test the tire radius from R13 to R17. The load speed of tire during experiments were from 0.8 to 2.5 mm/s according to the ČSN/STN 63 1511 standards. The outputs can be dependence of radial stiffness on velocities and inflation pressures.

The high speed requires a high safety precaution - construction of test machine. The tires are testing for different values of inflation pressure, under inflated tire and overinflated tires are tested. There is a risk of tearing the tire casing during high speed tests. Don’t exceed the manufacturer’s recommended tire inflation pressure. Be carefully during tire inflation too.

Therefore, the test machine has a safety steel frame – grating around the machine and several emergency off buttons. The door must be closed and it is not possible for the operator to be inside during tests.

The high speed requires a high safety precaution



tire replacement by the operator, **stop mode on the control panel**

special frame that dampens the vibration from the rotating drum

Emergency off buttons at outside and inside of test machine

during test – door must be closed

steel ring is mounted on the **frame around the brake (very hot !)**

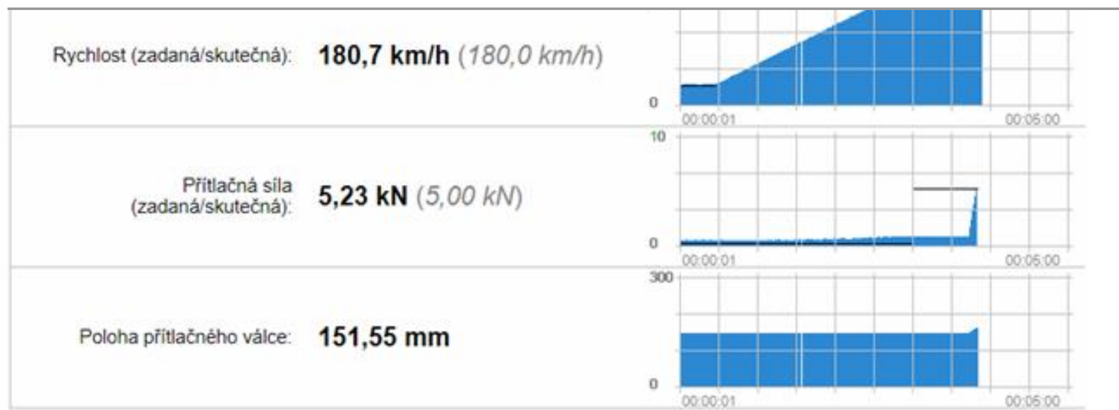
During tests – there are a risk of tearing the tire casing during high speed tests.

There is recommend the use of ear-protectors if the operator is near the test machine.

Safety and warning information in Czech language –

1) beware, dangerous space,
2) beware, electrical equipment,
3) the **risk of squeezing the upper limbs**,
4) a pressure vessel is used in the device construction,
5) attention, **risk of pulling**,
6) attention, **risk of burns, hot surfaces**.

The control panel is from the control room behind the glass because there is a lot of noise during the tests and safety is need.



Control panel with emergency off button, detail of control panel display and on the bottom right: computer online output data from test on monitor as sample online graphs and data values

After every test, the drum is stopped by special brake

There is a risk of burning in the vicinity of the brake, as a drum that weighs over 1.2 tones stops from speed 30 km/h. Even so, the brake is VERY HOT. Therefore, a steel ring is mounted on the frame around the brake. There is excessive bearing heating may occur. Both are marked as very high level of risk.

The safety and warning information on injuries are provided on all devices.

The operators have to be very careful during composite and tire tests and printing process too.

http://www.ceskatelevize.cz/ivysilani/1097181328-udalosti/218411000100301/obsah/603964-motoriste-a-silne-mrazy

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KRMELA, J. Tire Casings and Their Material Characteristics for Computational Modeling. Scientific monograph. Printing House The Managers of Quality and Production Association, Czestochowa, Poland. 2017, ISBN 978-83-63978-62-4. With test videos at DVD. The book is available in Polish libraries.

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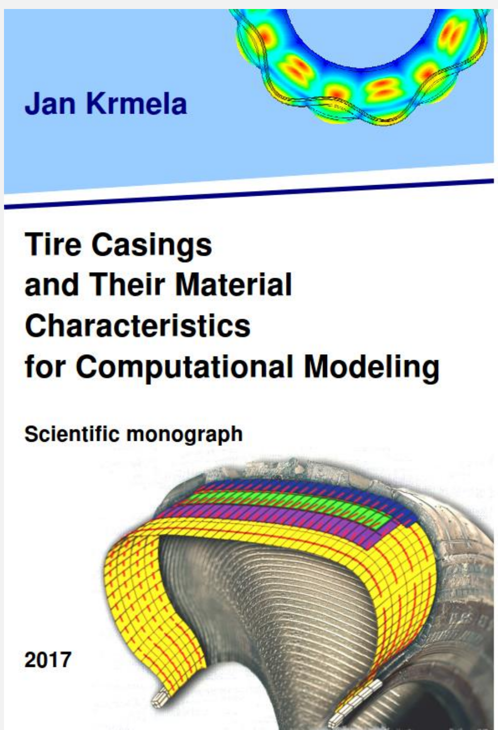

Title: **Ergonomics Modify Conditions of Work and The Safety at Work : Textbooks for university students**

Author: doc. Ing. Jan Krmela, Ph.D.

Book type: Textbook for university students **(VŠ učebnice)**

Edition: First, March 2021

Publisher: **Oficyna Wydawnicza Stowarzyszenia Menadżerów Jakości i Produkcji** (Printing House The Managers of Quality and Production Association), Czestochowa, **Poland**

This book has not been checked and corrected for spelling errors.

ISBN 978-83-63978-87-7

ISBN 978-83-63978-87-7

ISBN 978-83-63978-87-7
9 788363 978877