

# **Experimental investigation of the influence of cooling process after rubber bushing elements postvulcanization on bonding strength.**

Bc. Filip Zubal

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Master's thesis  
2019



**Tomas Bata University in Zlín**  
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- 2. Analyses of the postvulkanisation process of rubber bushing elements in-situ**
- 3. Transfer the complete postvulkanisation process including all processing parameters in to laboratory condition by using of specified test specimen geometry**
- 4. Definition of testing methodology, performing of testing, evaluation of determined data**
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[3] James Lindsay White, Rubber Processing: Technology, Materials, and Principles, Hanser Gardner Publications, 1995, ISBN-13: 978-1569901656

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## **ABSTRAKT**

Tato diplomová práce se zaměřuje na post-vulkanizaci a vliv ochlazování na tuto operaci. Teoretická část je zaměřena na popis kaučukové směsy, přípravu povrchu před pojením, popis materiálových vad a popis výroby stabilizátorů ve skutečném provozu, pro kterou je tato diplomová práce zaměřena.

V experimentální části je uveden návrh testovacího přípravku a jeho využití pro laboratorní podmínky. V další části byl sledován optimální lisovací čas a dále vliv chlazení na pojení pryž-kov. Nejdůležitější poznatky jsou shrnuty v závěru.

Klíčová slova: Pryž, ocel, post-vulkanizace, adheze, pojení pryž-kov

## **ABSTRACT**

The presented master's thesis is focused onto post-vulcanized operation and influence of cooling on its operation. The theoretical part is focused on describe rubber compound, surface preparation before bonding, material failure and describe of stabilizer bar manufacturing in real manufacturing.

In the experimental part is mentioned design of testing sample and its usage for laboratory conditions. In the next part, optimal post-vulcanized time was detected further influence of cooling on the rubber-metal bonding. The most important findings are summarized in conclusion.

Keywords: Rubber, metal, post-vulcanization, adhesion, rubber-metal bonding

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I hereby declare that the print version of my Bachelor's/Master's thesis and the electronic version of my thesis deposited in the IS/STAG system are identical.

In Zlín 15. 5. 2019

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Filip Zubal

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## INTRODUCTION

This work is focused on post-vulcanization process which is used for manufacturing stabilizer bars with bonded rubber bushing elements and its influence of cooling process for the final product. Multinational company which concern stabilizer bar for automotive industry and for which is this work written, trying to add cooling process to manufacturing which will faster the production, however this issue has not been study yet. Therefore, this work will bring new proposals for future fabrication.

Rubber bushing elements are more often used in vehicle industry in these days. Specially for reduction of vehicle noise and vibration. Bushing parts are highly dynamically loaded components and commonly are composed from varied rubber sheets. The mechanical behavior of this rubber parts are based on dynamic loading conditions caused due to complex processes. The most affected region in such more layers component is the interface connection between rubber-metal, which transfers the high dynamic loading condition applied on the loaded part.

Theoretical part is focused on general description of manufacturing of rubber components, metal surface preparation before bonding (called post-vulcanization) and bonding process itself, supplemented by description of producing in real company. Experimental part describes process of testing samples making in laboratory conditions and their testing on the influence of cooling them after post-vulcanization.

## **I. THEORY**

## 1 BUSHING ELEMENTS

Rubber bushing elements are more often used in vehicle industry in these days. Especially for reduction of vehicle noise and vibration. Bushing parts are highly dynamically loaded components and commonly are composed from varied rubber sheets. The mechanical behavior of this rubber parts are based on dynamic loading conditions caused due to complex processes. The most affected region in such more layers component is the interface connection between rubber-rubber, which transfers the high dynamic loading condition applied on the loaded part. (9)



*Figure 1 Bushing elements (29)*

In next chapters production of bushing parts will be described with write up theory.

### 1.1 Elastomers

Elastomers or rubbers are amorphous polymers to which various ingredients are added, creating what the rubber chemist refers to as a compound. After vulcanization, these materials become **rubber**. At low temperatures are elastic and at high temperatures plastic.

They are commonly used because of their ability to undergo big elastic deformations (you can stretch them, and they will return to their original form).

Rubber properties can be improved by adding fillers per application.

In practice we can divide them to **natural** and **synthetic** rubbers (elastomers). (1)

## 1.2 Rubber compounds

The raw rubber itself has just several properties which are not adequate for applications in manufacturing. Therefore, it is necessary to add additives to compound of rubber to improve final properties or improve workability. Every compound of the rubber depends on the price, on requirements of customers and on the area of application.

Every rubber or elastomer has its own recipe. Every recipe contains raw rubber, filler, curing system, antioxidants, anti-degradants and more additives depending on the properties.

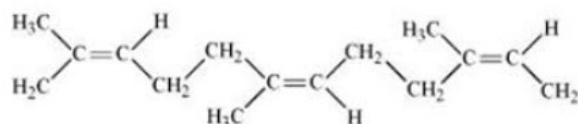
Basic component of every rubber compound is raw rubber. Other additives (components) are added in **parts per hundred rubber**. Example *Table 1. (2)*

*Table 1 Rubber compounds (2)*

Materials	Content (phr)
Rubber	100
Filler	0-150
Process oil	0-10
Activators	0-5
Antidegradants	0-3
Accelerators	0-4
Vulcanization Agents	6-10

## 1.3 Natural rubber (NR)

Natural rubber still represents about one third of the rubbers used in the rubber industry. This product is specially used in tires industry as a blend with SBR and BR. Further in manufacturing hoses and transport strips.



*Figure 2 Natural rubber formula (1)*

NR is product from the tree which is called *Hevea brasiliensis*. This tree grows mainly in Asia and South America. After that natural rubber is obtained by coagulation with formic acid. Small quantities of anti-branching agents are added to the latex before coagulation in order to keep the viscosity of the natural rubber. (1)

## 1.4 Butadiene Rubber (BR)

BR is the third largest volume rubber used by the rubber industry and it is made from butadiene monomer. This rubber is made by solution polymerization in hydrocarbon.

Butadiene Rubber is mainly used in tire application as a blend of SBR. BR has great capability to absorb high oil contents and high filler. Further dynamic properties and wear resistance.

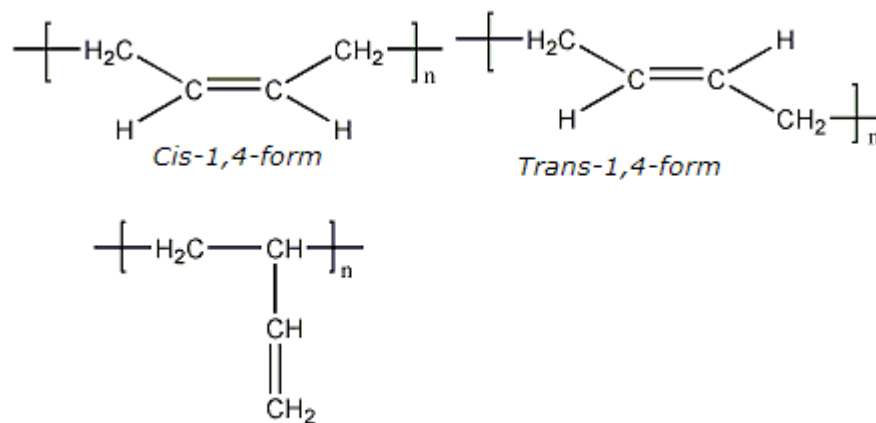


Figure 3 Butadiene rubber formula (1)

This two - types of rubber, are most widely used for manufacturing of rubber bushing elements thanks to their properties. Most commonly for bushing elements is combination of NR and BR, principally 60 phr natural rubber to 40 phr butadiene rubber.

## 1.5 Fillers

Fillers are added to rubber to reduced cost of elastomer product. Other important functions of fillers are to improve its properties:

**higher modulus**

**higher tensile strength**

**higher abrasion strength**

**lower stickiness**

We can divide them in two categories according to their color:

- **black fillers:** Carbon black
- **white fillers:** Silica, Kaolin, Talc, Calcium Silicate

Next, we can separate fillers according to their effect on the properties of rubber compound in three categories:

- **reinforcing fillers** - These additives improve qualities of rubber. Their size is from 0,01 to 0,1  $\mu\text{m}$ . Representatives carbon black, silica.
- **semi-reinforcing fillers** – These additives, has worst abrasion resistance then Reinforcing fillers. Size of the fillers is from 0,1 to 1  $\mu\text{m}$ . Representatives hard kaolin coarse carbon black.
- **non-reinforcing fillers** – Main function of these additives is to reduce cost of elastomer product. Size of the fillers is from 1 to 10  $\mu\text{m}$ . Representatives Talc or  $\text{CaCO}_3$ . (2)

### Carbon black fillers

Carbon black filler are the most important filler in rubber industry. Because of that most of rubber products are black. Carbon black improve rubber properties such as wear resistance, tear resistance, tensile strength and it also protect rubber from UV radiation.

Most widely used is carbon black in tire industry.

The most common production, of carbon black is **Furnace Black process**. This method forms carbon black by blowing petroleum oil or coal oil as raw material into high-temperature gases. (2;3)

## 1.6 Vulcanizing agents

These additives are creating bonds between the macromolecules of elastomer by chemical reaction. Every vulcanizing agent gives to rubber product different properties. Because of that, for the specific type of rubber can be used only the specific vulcanizing agent.

Most widely used vulcanizing agent is sulfur, joining with activators and accelerators. These additives reacts with chains of elastomer and creates crosslinks. Sulfur presents about 90 % of used vulcanizing agents. Other 10 % are based on peroxide curatives. Sulfur is commonly used with natural rubber (NR), polybutadiene rubber (BR) and styrene-butadiene rubber (SBR). (2;4)

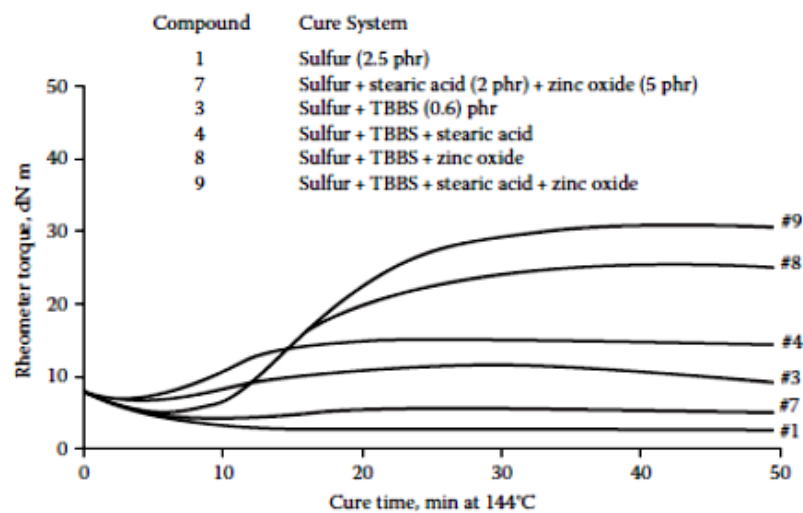
Other used vulcanizing agents are:

- **Diamines.** Mostly added to FKM
- **Zinc oxide.** Mostly added to IIR (Butyl Rubber), CR
- **Peroxides (Dibenzoyl peroxide).** Mostly added to EPDM (Ethylene Propylene Diene Rubber) and others. (2;4)

## 1.7 Activators

The most widely used activators are Zinc oxide and stearic acid. This pair of additives speeds up the cure of rubber that zinc oxide reacts with the stearic acid during curing process to solubilize divalent zinc ion. After that zinc ion reacts with accelerator and create sulfur cross-links between elastomer molecular chains.

Activators are added to compound in small concentrations between 0,2 to 5 phr. Without an accelerator, the activators are ineffective in crosslinks produced. Example *Figure 4.* (2)



*Figure 4 Effect of activators on cure time (5)*

## 1.8 Accelerators

Accelerators can be divided to primary and secondary accelerators. Primary accelerators usually provide considerable scorch delay, medium to fast cure, and good modulus development. Secondary accelerators mostly produce curing stocks.



## 1.9 Retarders

Retarders are additive materials which are used with sulfur vulcanized polymers. By adding it in to rubber compound, retarders provide longer scorch safety with little change in rubber properties.

These materials are mainly used with thiazole-based cure system. Typically, retarders are salicylic acid, benzoic acid and phthalic anhydride. (2;4)

## 1.10 Antidegradants

Antidegradants are used for their ability to protect elastomers from aging which is caused by oxygen and ozone.

**Antioxidants** (protection against oxygen) can be divided in two groups, primary and secondary. Primary antioxidants act as chain terminators, and secondary antioxidants act as hydroperoxide decomposers.

**Antiozonants** protects all of the external vulcanized rubber components from ozone-induced cracking. (2;4)

## 2 VULCANIZATION

Vulcanization is process mostly used for rubbers and elastomer materials. During the process, strong chemical bonds are created between molecules of raw rubber thanks to vulcanizing agents. This operation is depending on the temperature, pressure and time of vulcanization. (10,11)

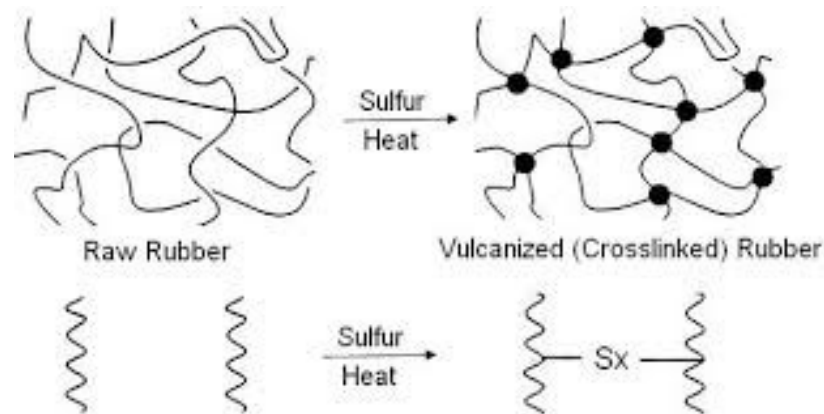


Figure 5 Vulcanization effect (10)

### Types of vulcanization:

- continual (in vulcanization tunnels and pressers)
- discontinuous (vulcanization in molds, hot water, steam and pressers)

At first the raw rubber must be molded into the required profile. Material molding can be waged under heat or under cold. After that the product is warming to the vulcanization temperature and endurance on this temperature. During endurance, vulcanization of material starts at reserved parameters (time, temperature and pressure). Finally, after vulcanization, the material is removed from mold.

Vulcanization process can be monitoring on the vulcanization curve. Vulcanization curve shows us the rising of crosslink density depending on the time. Elastomer compound is placed into the measure rubber process analyzer device. This device started to rotated and the rubber testing sample is measured under pressure and temperature. (10,11)

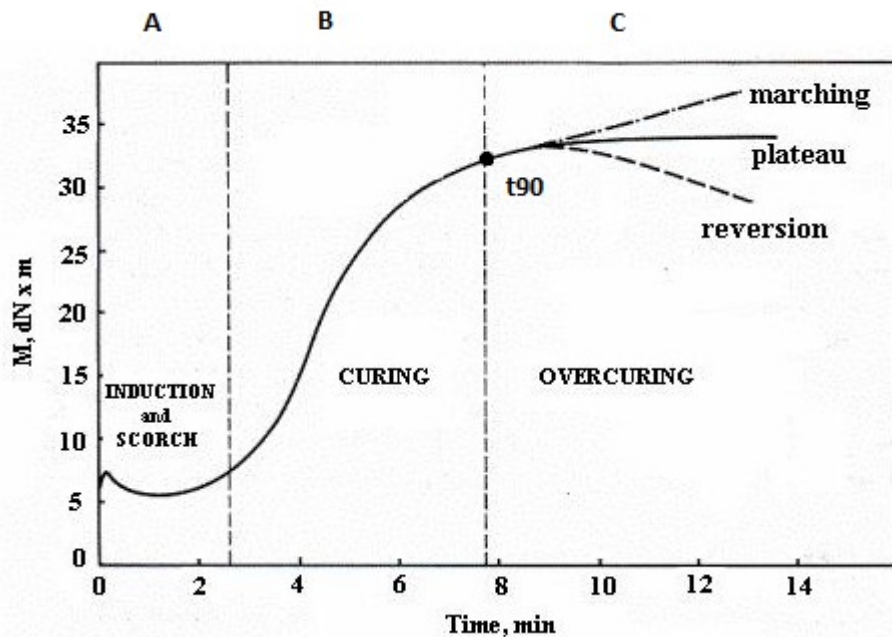


Figure 6 Vulcanization curve (10)

**A** – This section is also called as induction period or safety of rubber compound. It is a period, when the compound is gradually heated, thereby decreases viscosity of compound. In this period does not take place crosslinking reaction, but only reaction of vulcanization agent with rubber and other ingredients. Here we can safely manipulate with the rubber compound.

**B** – In this section is formed three-dimensional network by bonding of rubber chains. Amount of vulcanization agent gradually decreases. Strength of network in this section gradually increasing. In point  $t_{90}$  is the optimum of vulcanization, where is 90 % of conversion.

**C** – 100 % of conversion, but curing reaction can continue in three different ways, which have effect on the structure of network.

**Marching** – If vulcanization agent is not completely consumed, curve of curing has an increasing tendency, network density increases and quality of vulcanizate properties decreases. The vulcanization agents, which have this effect are for example zinc oxide or manganese oxide.

**Plateau** – Here is vulcanization agent completely consumed for reaction. The course of curing curve and properties of vulcanizate remain unchanged. The vulcanization agents, which have this effect are organic peroxides.

**Reversion** – This effect is called reversion and is typical for natural rubber vulcanized by sulfur. During the reversion decreases density, network structure, module and vulcanizate degrades. (10,11)

## 2.1 Post-vulcanization

Special operation mostly used for rubber products. During post-vulcanization, rubber products has its own profile of finished products but it is not fully vulcanized. Products are removes from vulcanized molds earlier, before  $t_{90}$  achieving.

This operation is widely used for bonding of rubber to another material. Such as metal, copper, cords and more. (10)

### 3 STABILIZER BAR SURFACE PREPARATION

#### 3.1 Stabilizer bar

Stabilizer bar or anti-roll bar is simple device, most commonly bended into the U shape. It reduces and balanced stress of wheels during ride across curves and disparities. Thanks to this, stabilizer bar improves grip and controllability of car. It connects opposite left and right wheels together thru short arms connected by a torsion spring. (29)

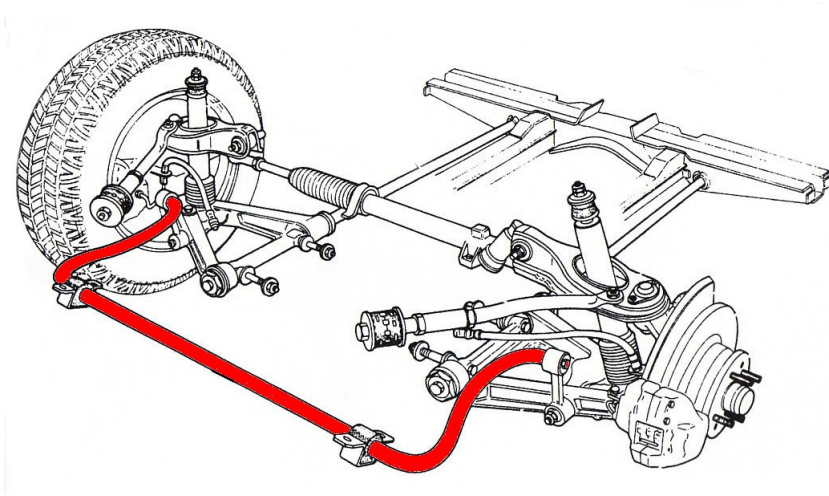


Figure 7 Stabilizer bar (29)

#### 3.2 Surface preparation

Surface preparation is one of the most important technological operation. The main reason to prepare metallic surfaces before bonding with elastomers is in shelf life of joint between metal and rubber. During the process we attend to remove all unwanted materials. Chemical and mechanical filths. Oils, oxides and all rusty surfaces. Which they can cause problems during vulcanization. After modifying, application of adhesive or primer is needed, because of the creating of oxides on the surfaces.

Chosen technology of the surface preparation influences:

- quality of conjunction
- reliability
- working life of the products

This chapter describes surface preparation of metallic part. Rubber parts are provided finished from external company.

Surface preparation is often divided in two groups. **Mechanical surface preparation** and **chemical surface preparation**. (6)

### 3.3 Mechanical methods

Mechanical methods mainly remove all dirt from surfaces of the products and improve mechanical properties. Next it creates suitable adhesion for layers and improve requirement for resistance against corrosion.

Mechanical methods includes: grinding, polishing, brushing, blasting and tumbling. (7)

#### 3.3.1 Grinding

The main purpose of grinding is to removal all inequality of the surface. This process uses grinding belts or discs with abrasive. Grinding can be divided into two groups. **Rough grinding**, which uses abrasive grain in the size from 24 to 200  $\mu\text{m}$ . And **smoothing grinding**, which uses abrasive grain size of 120 to 240  $\mu\text{m}$ .

Grinding can be used even for the hardness materials and by this operation, very quality surfaces are made. (8)

## Common Grinding Wheels

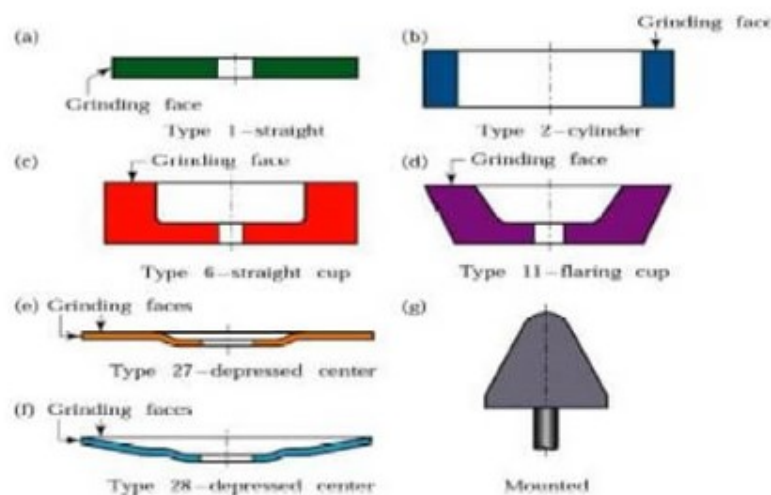


Figure 8 Types of grinding wheels. a) Straight wheel, b) cylinder wheel, c) Straight cup wheel, d) Flaring cup wheel, e,f) Depressed center wheel g) Mounted

(8)

### 3.3.2 Polishing

Polishing is very similar operation as grinding, but during this process material is removal in very small cases. By this process roughness of the surface is on high level (under Ra 0,1  $\mu\text{m}$ ). Quality depends on speed of the tool and the polishing paste. Paste contains a lot of varieties of abrasives (calcium oxide, alumina, ferric oxide, chromium oxide).

Surfaces getting their final appearance after polishing and along with grinding these methods are the most expensive. (8)

### 3.3.3 Brushing

Brushing is operation which is mainly use for two types of surface preparation. For removing of dirt parts from products like corrosion and old coat. Further for refinement and for unification of surfaces after grinding. (8)

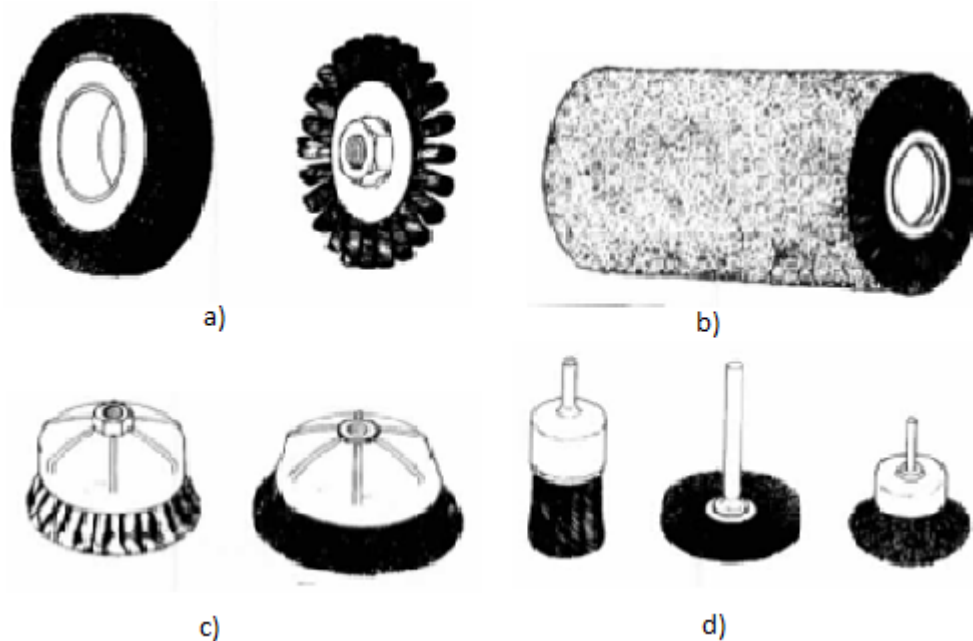


Figure 9 Types of brushes. a) Wheel brushes, b) Wide face brushes, c) cup brushes, d) Stem mounted brushes

### 3.3.4 Blasting

Blasting is technology which is widely used for cleaning and for preparation of surfaces for thermal injection. This operation is the most effective mechanical method for removing corrosion. The most commonly blasting materials are abrasives, silica sands, cast iron grits and more. (7,8)

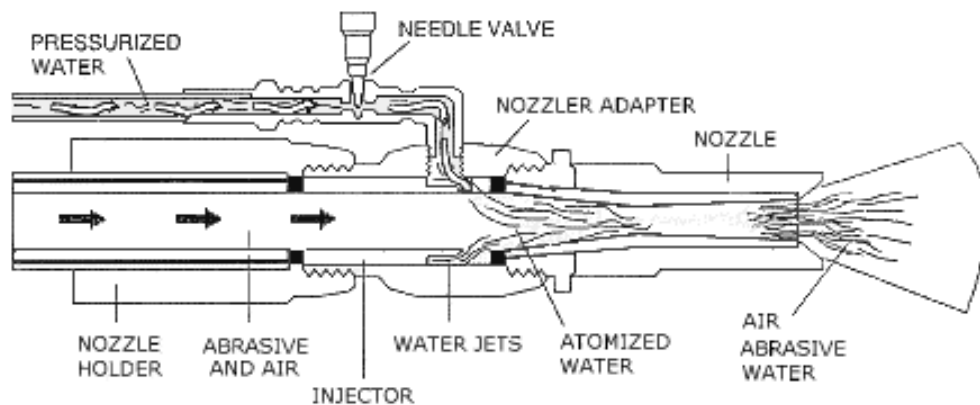


Figure 10 Abrasive blasting (7,8)

### 3.3.5 Tumbling

Tumbling is operation for polishing and smoothing rough surfaces by tumbling parts and tumbling liquid. This technology is appropriate for mass production and for complicated parts. (8)

#### Advantages:

- reduction in cost
- hardening surface
- corrosion resistance
- reduction in rejects pieces

#### Disadvantages:

- unequal removal from the part surface
- damage of products



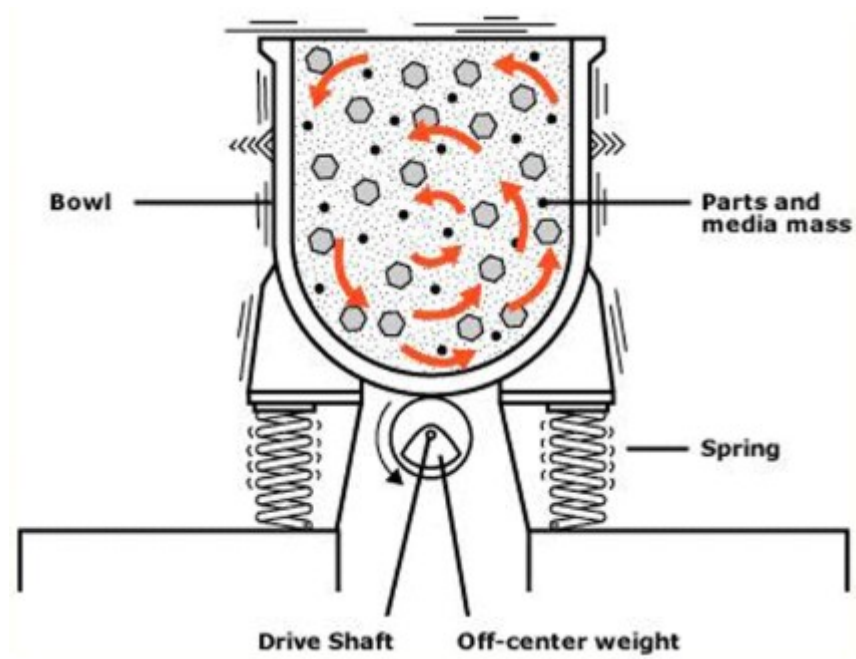


Figure 11 Tumbling device (8)

### 3.4 Chemical methods

Chemical methods are based on chemical reaction between surface of the material and reagent. However, every material has his own specific chemical reactivity, because of that the choice of a right agent is very important. (8)

#### 3.4.1 Degreasing

Tumbling is removing of all kind of dirt from material surface. This dirt can be cause by physical absorption (fat natures substances), or by adhesive forces (powder, inorganic dirt, metal splinter). The main purpose of tumbling is to release dirt from the surface of material and conversion him to the emulsion. (8)



*Figure 12 Degreasing effect (12)*

Degreasing is often divided into three types:

- degreasing in organic solvent
- degreasing in water alkaline substances
- degreasing by emulsion

### **3.4.2 Pickling**

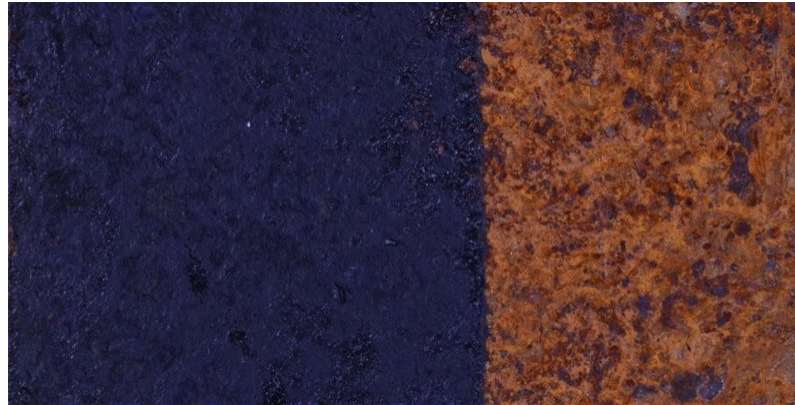
Pickling is removing of corrosion from the material surface by chemical or electrochemical method. Material is often treated by acids, salt acids or alkaline agent. This operation is mainly used for removing of dross and corrosion from cast iron. (8)



*Figure 13 Example of pickling effect (22)*

### **3.4.3 Rust converting**

Rust converting is operation for removing corrosion from material surfaces. This corrosion is removed by acids, specially phosphoric acid. Rust converting also includes corrosion inhibitor, humectant and degreasers. (8)



*Figure 14 Rust converting (23)*

### **3.5 Laser preparation**

Laser ray is widely used thanks to his specific properties. Laser is capable to work with metal and non-metal materials with high quality of surfaces. This method is mostly used for cutting, hole-drilling, welding, engraving and for surface preparation (like cleaning and roughing). Laser surface preparation is appropriate method, which can replace chemical and mechanical methods. These methods can damaged material surfaces, and changed their properties (like corrosion, lower surface density and more). (24)

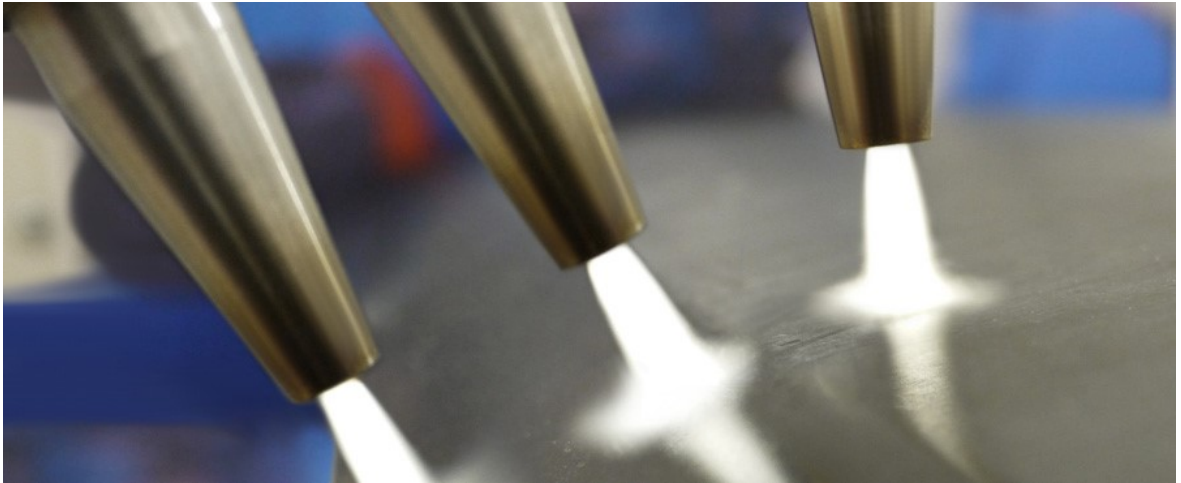


*Figure 15 Laser surface preparation (25)*

### **3.6 Plasm preparation**

This operation is mostly used for activation of the metal surface before gluing, varnishing, coating or for technological operations where higher surface tension is needed. By plasm, the dirt can be also removed from surfaces.

Plasm particle are connecting with closed strings of activating material and creates open ends that are connect with glue, coating medium and more. (26)



*Figure 16 Plasm preparation (26)*

## 4 ASSEMBLING OF THE PRODUCT

### 4.1 Post-vulcanization

Post-vulcanization (PV) is special process for bonding steel with rubber. This operation is very similar to the vulcanization. However, the rubber is partly vulcanized and has full profile. Adhesives for post-vulcanization are limited compared to vulcanization.

Usually, the surface of the vulcanized rubber is modified, to remove all unwanted substances. It can be used by mechanical or chemical methods. Most used method in chemical preparation is chlorination of the rubber surface. By standard mechanical method the surface of the elastomer is treated by sand paper. After that modified rubber is bonded with steel, which is covered by adhesive material. Deformation of the rubber is about 10-20% during compression, this ensures adequate contact of the surfaces, supply heat creates strong bond.

Post-vulcanization is carried out in autoclaves, ovens or inductive heaters. (15)

#### **Advantages:**

- cheaper forms for production
- strong bonds

#### **Disadvantages:**

- more technological steps during production

#### **Usage of post-vulcanization**

Post-vulcanization process offers many options for designing of parts. Such as:

- silent blocks
- fixtures of engine
- stabilizer bars

### 4.2 Connecting medium for PV-Chemosil

Chemosil products produced by LORD company are appropriate bond medium for PV technology. Selection of bond medium depends on type of rubber, properties of base surface, temperature, pressure and time. (15)

**Representatives:**

- Chemosil X6025
- Chemosil X6070
- Chemosil 411
- Chemosil 211 and more

**Some importantly parameters for PV bonding:**

- Rubber composition- NR, CP, EPDM, NBR, SBR
- Chemosil 211 is foundational layer of primer.
- Application of Chemosil X6025 for low temperature (100 °C), and low-pressure bonding
- Recommended temperature for Chemosil 411 is over 120 °C

Metal rubber bonding can be divided into two categories. Primer/cover (two-layer systems) and single-layer systems.

For primer/cover systems primer layer contains substances which creates strong and durable bonds with metal surface. It is necessary to charged primer layer closed to metal surface compare to rubber. Cover layer contains substances for strong bonds with rubber.

Two-layer systems are more resistant then single-layer systems. Such as hot oils resistant and influence of salts. However, this application is much more expensive. (15)

**Recommended thickness of Chemosil**

*Table 2 Optimal thickness of primer/cover layer (15)*

Chemosil	Type of vulcanization	Vulcanization temperature	Thickness
Primer and 211			Minumum 5 µm Optimal 8-10 µm
222 or 220	A, B, C	130-180 °C (Optimal temperature to 170 °C)	Optimal 10-15 µm
411	A, B, C	130-180 °C (Prefer temperature 200 °C)	Minumum 10 µm Optimal 15-20 µm
X6070	A, B, C	130-170 °C	Optimal 15-20 µm
X6025	A	90-120 °C	Optimal 15-20 µm

*A - Compression molding, B - Injection molding, C - Transfer molding*

### 4.3 Adhesion

Two things that they are necessary in the creating of bonds between two materials. At first the **wettability** which includes creating of tight contact between molecules of adhesive part and material. Second **hardening** can be caused by chemical reaction or by lost of solvent, or by cooling.

After created of contact between gluing materials, Van der Waals forces and other forces are created. For example, chemical bonds that are starting to create between two surfaces during hardening. (17)

### 4.4 Chemical adhesion

Chemical reactions in the model of adhesion encourage creation of covalent bond, ionic bonding or hydrogen bond. Ionic bonds had thickest energy, second strongest energy creates covalent bonds and the last one are hydrogen bonds. With these bonds, we get the higher energy instead of Van der Waals forces, which they are sources of the physical adsorption. (17)

### 4.5 Adhesion between rubber-metal

Rubber- metal bonded assemblies are more commonly used in industrial applications in these days. especially for their great attribute to reduce vibrations or noises. Therefore, this process is poorly understood, and it is slowly evolved.

Most commonly used metal is steel specifically, for the price and properties. Function of the metal part is to transfer used force to the rubber part.

Operation which creates connection between rubber and metal surface is called post-vulcanization. Metallic surface is often coated by bonding layer (mostly used epoxides). As you can see on the picture below this operation requires interfacial crosslinking reaction chemisorption reaction and diffusion. (17)

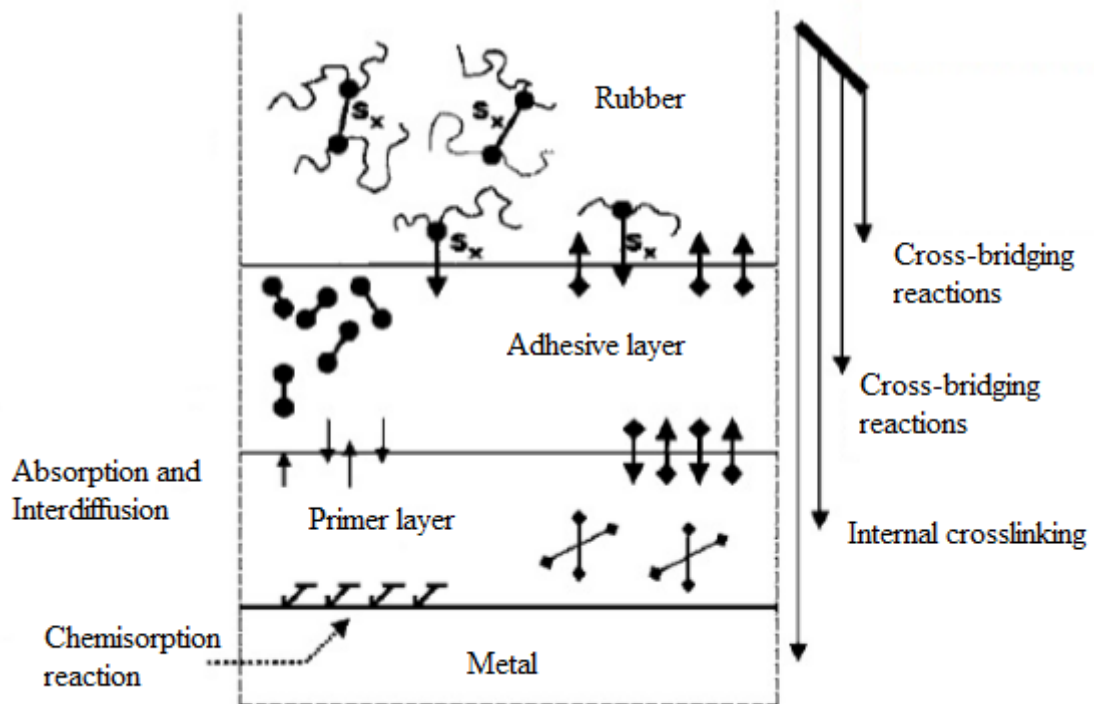


Figure 17 Adhesion between rubber and metal (17)

## 4.6 Epoxy resin

Epoxy resins (EP-resins) are polymers containing unreacted epoxy units, i.e. two carbon atoms and one oxygen atom. These are curable resins (thermosetting resins) that react with a hardener and eventually with additives that are used for forming a thermosetting polymer. Epoxy resins are polyether, typically with two end epoxy groups. The curing agents are the reactionary elements and form the plastic with the resin. (18,19)

### Application of powder paint - epoxy resin by electrostatic spraying

The principle of this technology is application in the electrostatic field with the presence of high voltage. At this point, the powder particles are electrically charged while the object which is lacquered is grounded. To create sufficient layer of powder on the object and to maintain it until the powder is hardened by using a curing oven, an attractive force is essential. (18,19)



### Methods of charging the powdery matter

The methods of charging the powdery matter can be divided into two basic groups:

#### Electrostatic charging (static, corona)

Due to the high voltage (30-90 kV), which focuses on the spray gun, the air that passes through the gun is being ionized. After the powder passes through the ionized air, the free ions are captured on a certain number of powder particles, creating a negative charge on the particles. The purpose of this process is therefore to achieve the greatest possible number of charged particles in the powder.

However, over-voltages could arise superfluous supply of free ions, resulting in complications in obtaining a high-quality surface finish. (18,19)

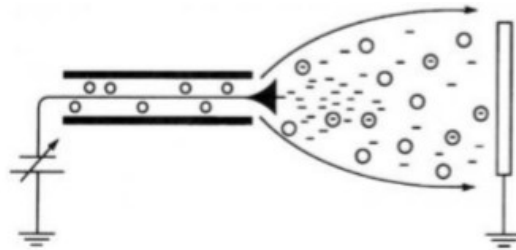


Figure 18 Electrostatic charging (18)

#### Tribostatic charging

Some types of powder particles with tribostatic effect are charged due to fast movement (friction, electro kinetics). It comes to friction on a special kind of insulator (usually PTFE) which is the cylinder of the spray gun lay with.

Tribostatic charging does not involve high voltages that could generate free ions or generate electric fields. The optimal performance can be achieved by regulating the air flow of the pistol, respectively ratio of powder and air. (18,19)

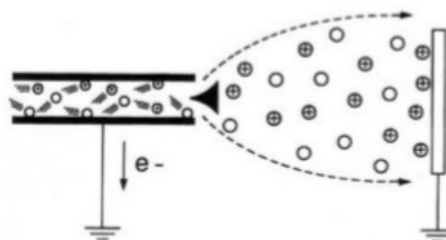


Figure 19 Tribostatic charging (18)

## 5 OVERVIEW ABOUT TESTING METHOLOGIES

Rubber and metal are bonded into a lots of form of products and in many cases a strong bond is essentially. It is necessary to create the same manners for testing in laboratory as are the products exposed in service.

In practice the types of material failure are commonly indicated by symbols:

- **R**- rubber failure- failure in rubber. Rubber tensile strength is smaller, then strength between rubber/cover, cover/metal or cover/primer.
- **RC**- failure between rubber and the cover- weakest point is between rubber and cover. The metallic surface is polished with very few or nothing left rubber on it.
- **CP**- failure between cover and the primer
- **CM**- failure between cover and metal- weakest point is between metallic part and cover. Main reason of this failure can be polluted metallic surface. (13,14)

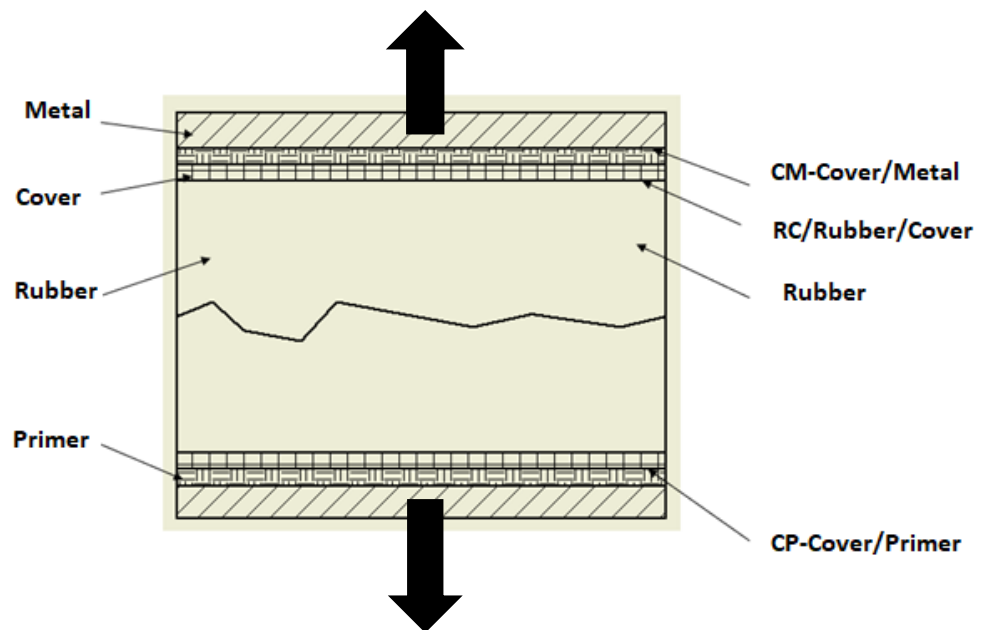


Figure 20 Types of material failure

## 5.1 Peel test

This method is marked as ASTM D429-B

Peel test using a test sample which is 6 mm thick and 25 mm wide. This testing sample is bonded to metal which is 1,5 mm thick and 25 mm wide. The sample is peeled 50 mm / min at tensile machine This test ends after separation of rubber from the metal part. (13)

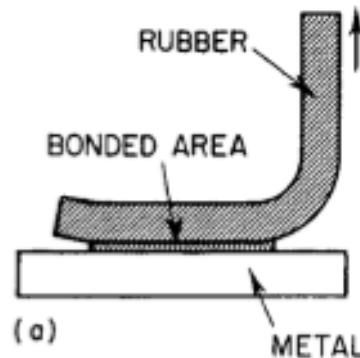


Figure 21 Peel test

Acquired dates presents the strength of adhesion between rubber and metal during separation of testing elastomer from the steel plank in 90 ° angle.

The amount of adhesion between rubber and metal:

$$Rb = \frac{F_b}{b} [N/mm]$$

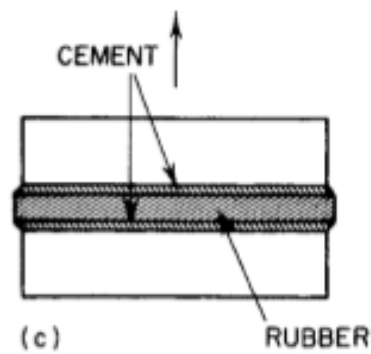
Where:

- $F_b$ - maximum strength (N)
- $b$ - width of testing sample

## 5.2 Tension test

This method is marked as ASTM D429-A

Tension test using a disc test sample which is a 3 mm thick and diameter is between 35 – 40 mm. The testing sample is bonded to metal parts (plates) which are roughly 0,1 mm smaller in diameter then the testing rubber. The sample is separated in tensile machine at the speed of 25 mm / min. This test ends after separation of rubber from the metal part. (13,14)



*Figure 22 Tension test*

Acquired data presents the strength of adhesion between rubber and metal during tension test.

The amount of adhesion between rubber and metal:

$$Ra = \frac{F_a}{a} N/mm^2$$

Where:

- $F_a$ - maximum strength (N)
- $a$ - site of testing sample

## 6 REAL PROCESS OF THE INDUSTRY

In previous chapters theory of manufacturing was describe. In this chapter the real production in production will be write up, with enclosed schemes.

### 6.1 Bushing priming

Bushing elements are delivers from external company. But it is necessary to charged them with connecting medium. In this case Chemosil 211 or Chemosil 411 from LORD company are used. This medium creates strong bonds between rubber elements and stabilizer bars.

Charging of connecting medium are to wage on GBL device. At first bushing elements must be insert to the underlay. Then, by robot shoulder are transpose into the pre-heating furnace. Here, the bushing elements are pre-heat on 70 °C (maximal). Preheat of bushing elements shall not exceed maximal temperature by reason of unwanted vulcanization of rubber.

After pre-heat, bushing elements are transport by robot shoulder into the priming chamber. Here, two priming guns which are swiveled at the angle of 45 ° spread connecting medium in two layers.

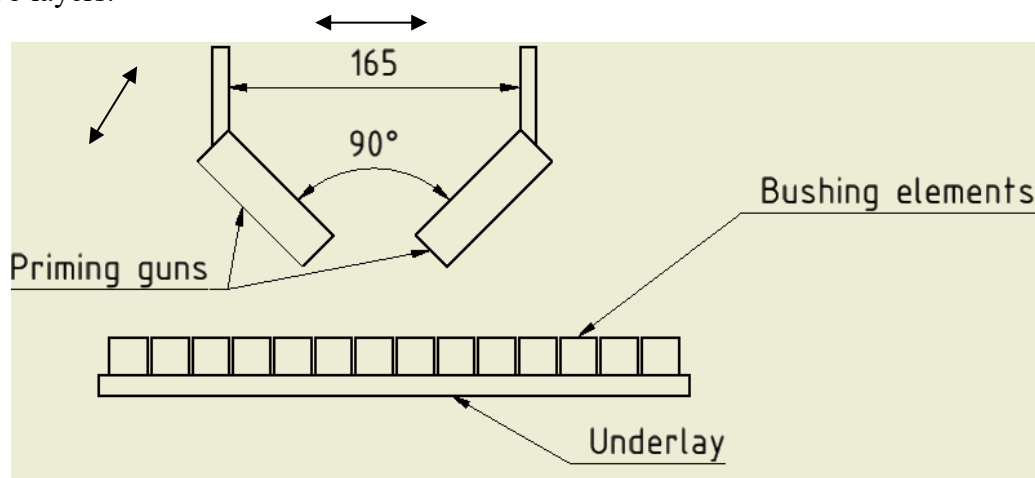


Figure 23 Bushing priming

## 6.2 Inserting of stabilizer and bushing components

Stabilizer bars placed in stand are manually folded into the conveyor belt. At the end of conveyor belt, weighting, centering and diameter control is needed. If anyone of this control parameters does not fit, bars are removed to the N.I.O. stand.

Rubber bushing elements are composed from boxes (which are placed on the stand), into the molds. In some projects the placement of elements is needed. By pressing of the black button, bushing elements are sends to the production

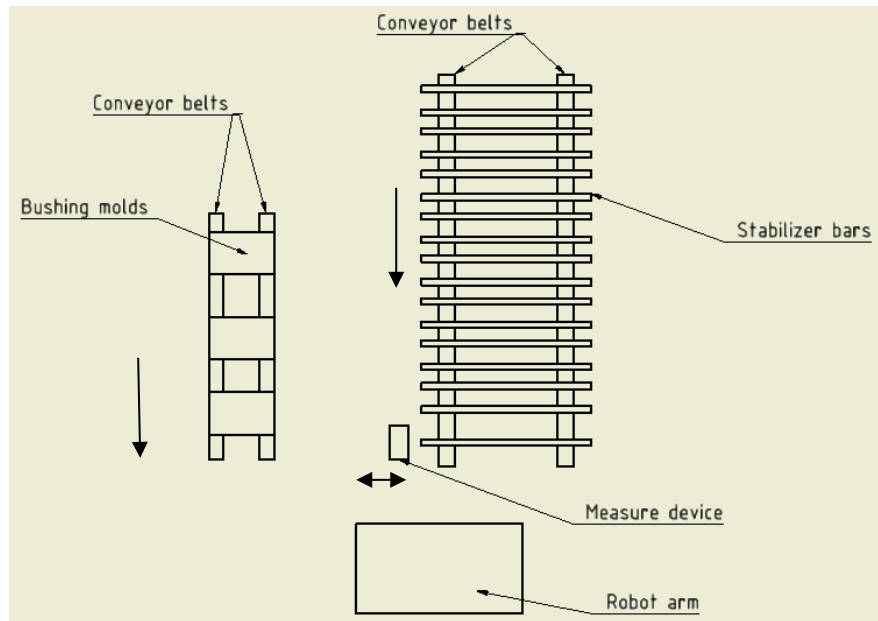


Figure 24 Scheme of stabilizer bar inserting

## 6.3 Surface activation

Robot arm insert stabilizer bar into the stand. Where laser ray, activate and roughen stabilizer surface. Specifically the surface roughen is important. Thanks to this operation, we extend adhesive surface.

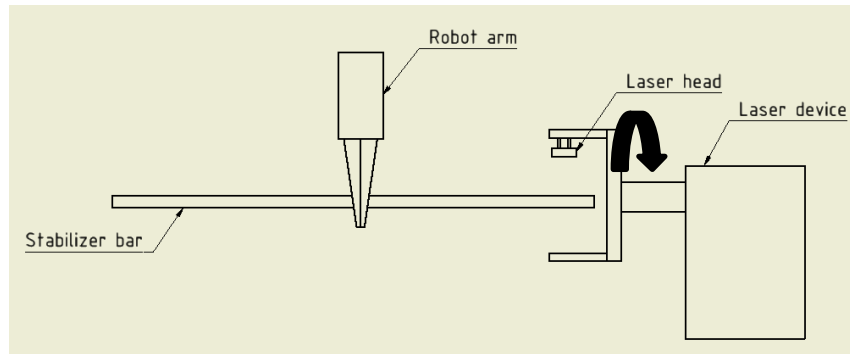


Figure 25 Surface activation

## 6.4 Induction heating

After surface activation, stabilizer bars are placed into spark coil which heats activate surfaces on required temperature. Spark coil has U shape and copper wire is bathed by epoxy resin.

Required heating temperature is between 250 °C to 270 °C. If is temperature high, it is come to burn of stabilizer coating and the product is rejected.

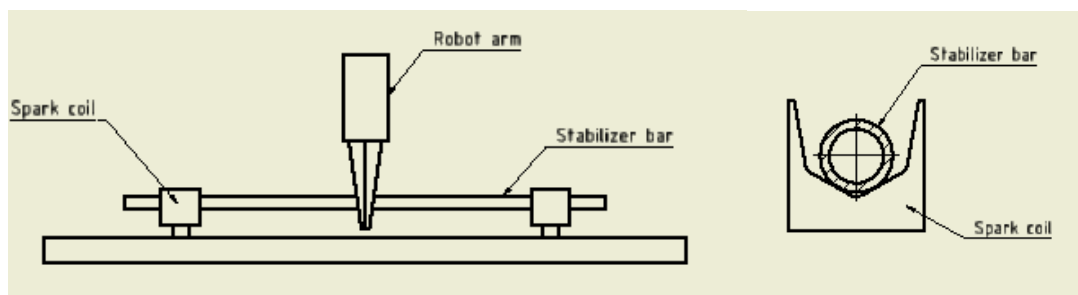
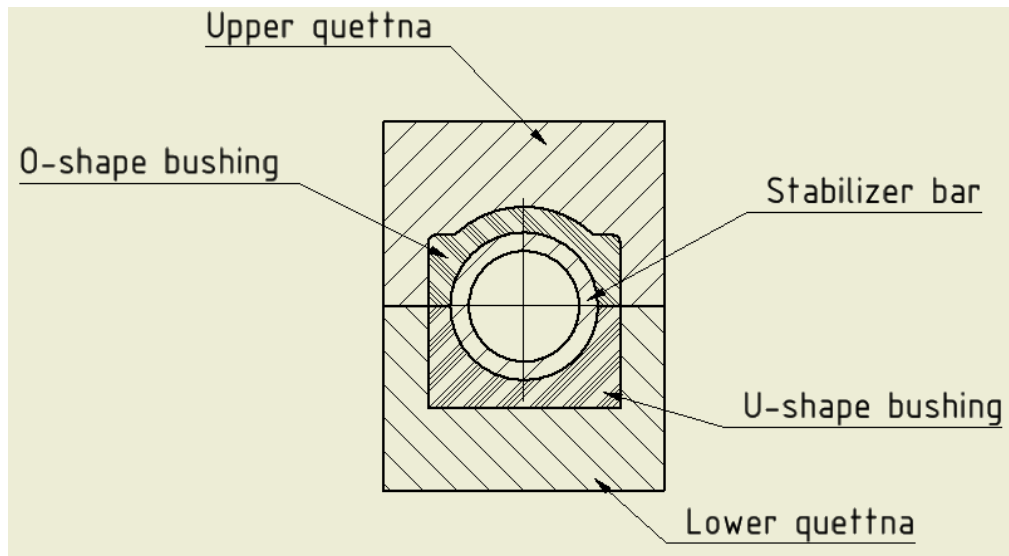


Figure 26 Stabilizer bar heating

## 6.5 Pressing of rubber bushing elements

Robot takes 4 rubber elements (two upper parts and two bottom parts) and insert the into the pressing tool named quettna. Then, the robot arm put stabilizer bar between upper and bottom of pressing tool, rubber parts are pressed into the stabilizer bar and quettnas are going to lock themselves by two locks.



*Figure 27 Pressing of bushing elements onto stabilizer bar*

## 6.6 Cooling and stabilizer bar control

After pressing, stabilizer bar with quettnas is put into the cooling rack. Cooling of stabilizer bar took 180 seconds and it is waged on air. After cooling, stabilizer bar is removed from quettnas and it is relocated by robot arm into the printer. Here thanks to robot arm tags are sticks onto stabilizer bar. After tag sticking stabilizer bars are put onto output belt and the final control is needed. It is necessary to control stabilizer bar coating (damage or burning) and rubber adhesion to metal by special control tongs. At the end stabilizer bar is control in special control device called leher. If everything is alright, finished and controlled stabilizer bars are put into the transport boxes.

## 6.7 Control of the final product

Stabilizer bar are tested by push-out test. Testing sample is cut into the required length and it is placed into the universal tension - compression testing machine from Zwick o. Fa. TIRA. Here the testing sample is damaged by stamp by its speed of 10 mm / min. After testing



cohesion of bushing part onto stabilizer bar and maximum strength for decoupling is controlled.

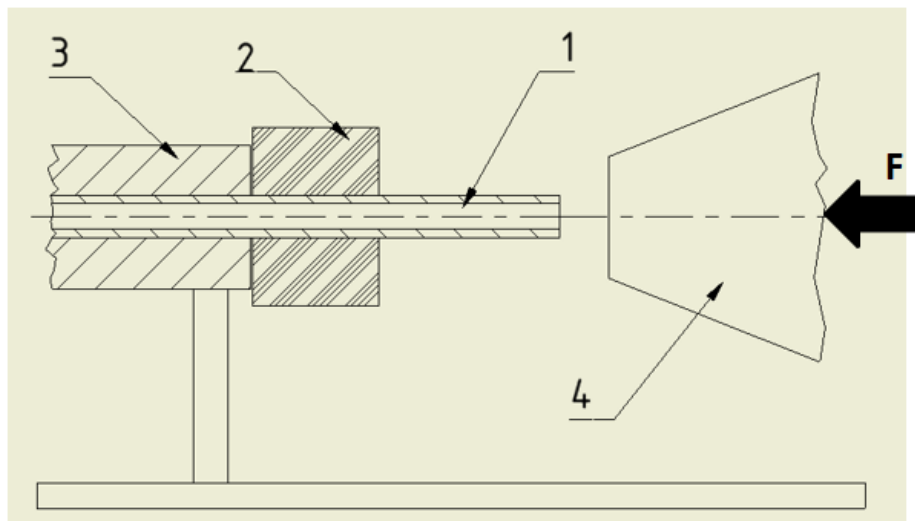


Figure 28 Push-out test

Table 3 Positions during push-out test

Position	Name
1	Stabilizer bar
2	Bushing
3	Mold
4	Stamp

## **II. EXPERIMENTAL PART**

## 7 TESTING MATERIAL

Rubber mixture was concocted industrially on internal mixers. Rightly recipe of material compound was not known, merely what is known that it is combination between natural and butadiene rubber.

Material rheological properties were finds out on MonTech device named MDR 3000. MonTech device measure viscoelastic properties of rubbers or polymers compounds.

MDR3000 is rheometer containing oscillating rotor inside the chamber in which is placed the sample of compound. Principle is based on measuring the torque, which is induced by constant frequency. The result is dependence of torque on time, which is expressed by vulcanization curve. From measurement is possible to determine parameters such as scorch safety ( $t_2$ ), cure time ( $t_{90}$ ), maximal torque ( $M_H$ ), minimal torque ( $M_M$ ) and so on. (20)



*Figure 29 Rheometer MDR3000 (20)*

From the *Figure 29* and *Table 4* we can see that the maximal torque  $M_{(H)}$  is about 15,8 dNm. Optimal vulcanization time  $t_{90}$  is 1,73 minutes (1 minute 44 seconds). Hereto this time, five minutes must be added thanks to mixture warming so the total vulcanization time is 6 minutes and 44 seconds.

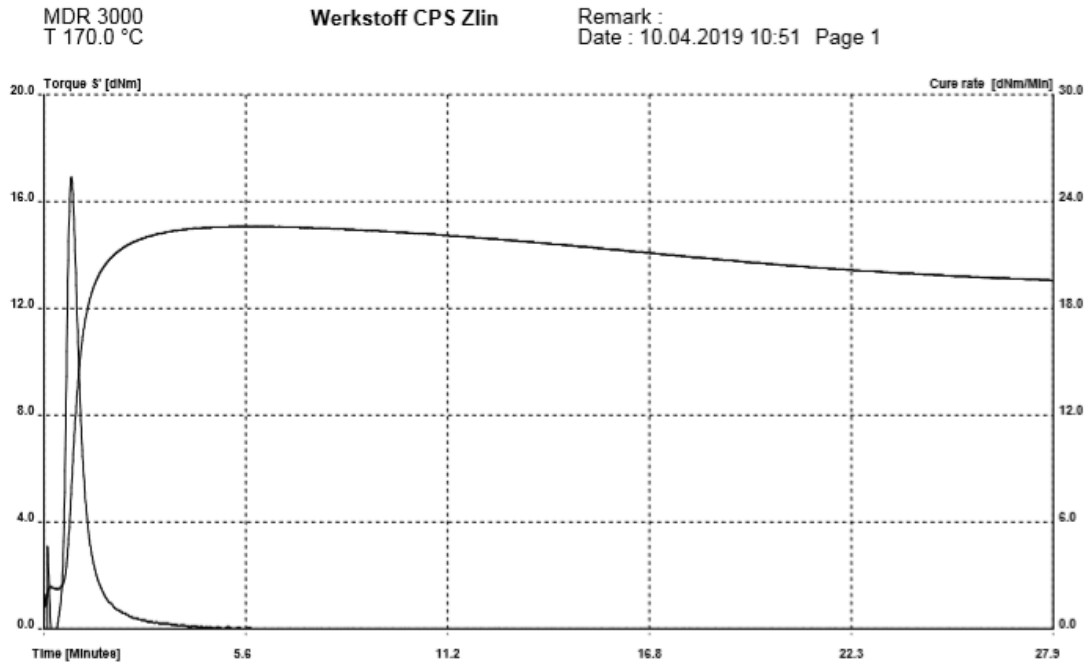


Figure 30 Vulcanization curve of testing rubber mixture

Table 4 Vulkanization parameters

	<b>M<sub>(M)</sub> minimal</b>	<b>M<sub>(H)</sub> maximal</b>	<b>Scorch Time (TS 2)</b>	<b>t50</b>	<b>t70</b>	<b>t90</b>
<b>Unit</b>	dNm	dNm	Minutes	Minutes	Minutes	Minutes
<b>Set-point value</b>	1,48	15,06	0,64	0,89	1,07	1,73

### 7.1 Vulcanization of testing material

After measurement, rubber mixture was vulcanized into optimal vulcanization time  $t_{90}$  (6 minutes and 44 seconds). Vulcanization has to be done in compression mold by dimension 150 x 150 x 6 mm and then vulcanized in warming pressure device under temperature of 170 °C and 300 kN of pressure.

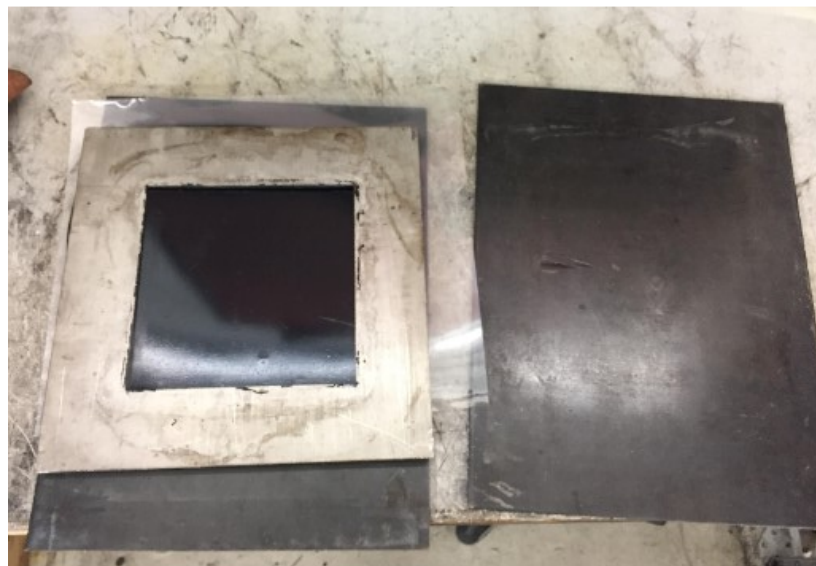
Table 5 Vulkanization parameters

Variable	Setpoint	Time (minutes)
Force	300 kN	6,73
DL1 Upper	170 °C	
DL1 Lower	170 °C	

Rubber slates were vulcanized in hydraulic presser LabEcon 300 from FONTIJNE PRESSES. This device is primarily used for pressing operation with polymers, rubbers and composites. Maximal configurable temperature is 300 °C and presser load 300 kN. Work-space of presser is 320 x 320 mm.



*Figure 31 Hydraulic presser FONTIJNE PRESSES LabEcon 300*



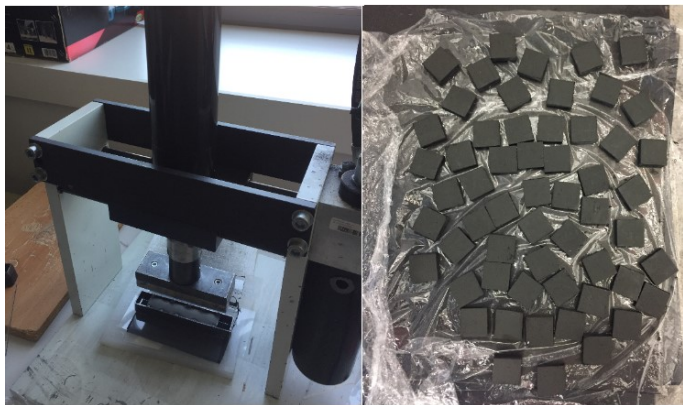
*Figure 32 Vulcanized slates*

## 7.2 Testing sample

After vulcanization vulcanized slates were cut in punching pressure device onto dimensions 20 x 20 x 6 mm and after that the special bonding medium called Chemosil from company LORD was applied onto testing samples.

Chosen dimensions for rubber material were subject on two criterions:

- Clamping onto testing device. Testing device allow angle of its load cells 6 mm maximal therefore the chosen width of sample was 6 mm.
- The measurements 20x20 mm were chosen so that the rubber, after being pressed, was not overlapping the edges of the steel plates, but the whole of the surface remained covered



*Figure 33 Left- punching pressure device, Right-rubber testing samples with applied Chemosil on its surface*

Before bonding rubber parts onto metallic parts, metallic samples were coated by paint used in real process for stabilizer bars

Dimensions: Metallic sample: 40 x 50 x 1 mm

Rubber sample: 20 x 20 x 6 mm

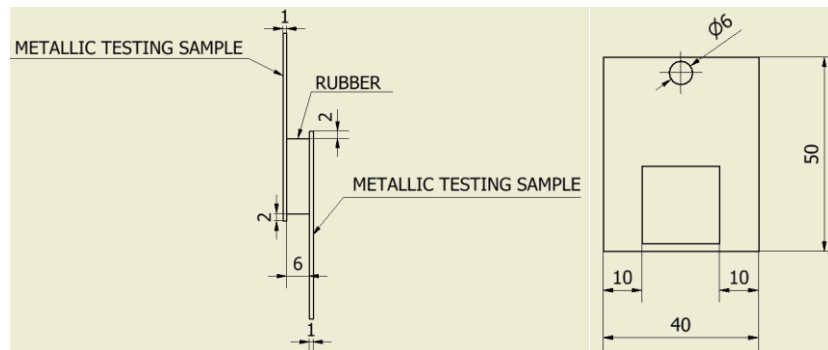


Figure 34 2D sketch of testing sample in Inventor 2018

In Figure 35 layers which are necessary for creates strong bond between rubber and metal can be seen. Images of the bonding is shown for our testing samples in simple 2D sketch. For creating such strong bonds, pressure and heating is important. To see in chapter 8. *Detection of ideal post-vulcanization time*

For primer/cover systems primer layer contains substances which creates strong and durable bonds with metal surface. It is necessary to charged primer layer closed to metal surface compare to rubber. Cover layer contains substances for strong bonds with rubber.

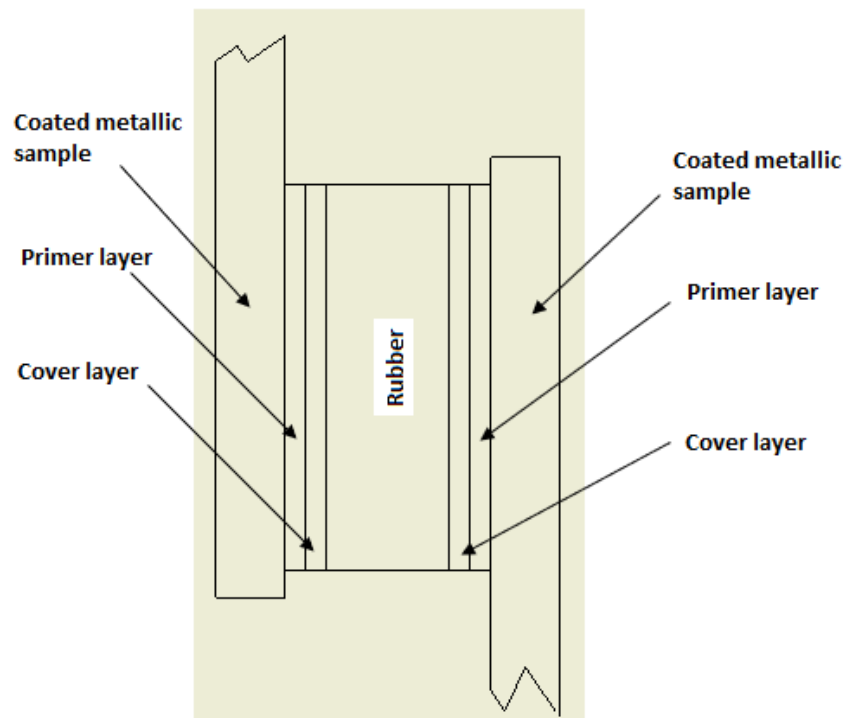


Figure 35 Layers of post-vulcanization bonding

## 8 DETECTION OF IDEAL POST-VULCANIZATION TIME

Before investigation of the influence of cooling process onto metallic and rubber bonding process, the right post-vulcanization time had to be found. At manufacturing the post-vulcanization time (where is stabilizer bar and bushing elements locked in quettnas) is 180 seconds. This time is of course different in manufacturing and in laboratory, thanks to used technologies. So, there were chosen four different times of bonding and these times, were compared to each other.

Chosen times for bonding were:

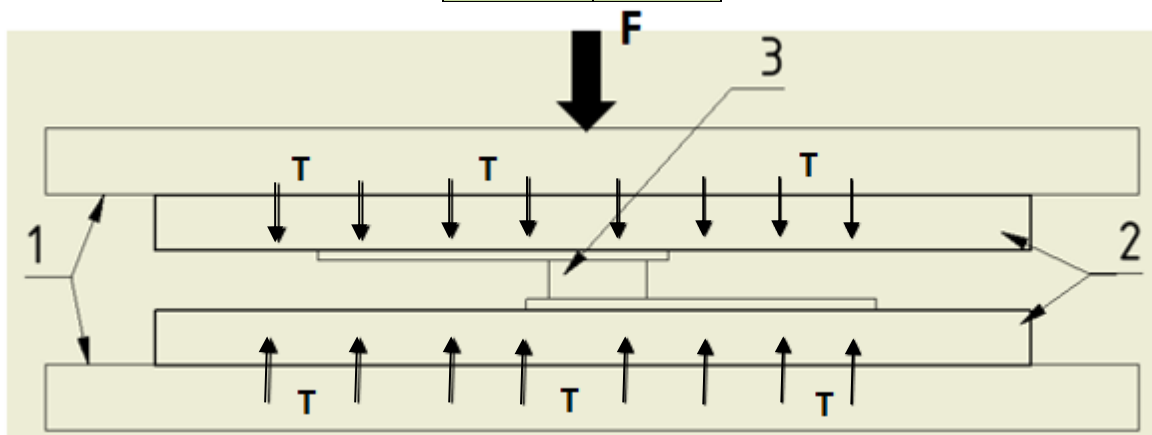
- 3 minutes-** three testing samples
- 3,5 minutes-** three testing samples
- 4 minutes-** three testing samples
- 5 minutes-** three testing samples

This detection has to wage on warming pressure device LabEcon 300 from FONTIJNE PRESSES company. At first the testing mold with metallic testing samples were heat up to recommended temperature by LORD company to 180 °C (took about 5 minutes), after that rubber sample with applied Chemosil on its surface was insert into testing mold and pressed by warming pressure device.

After pressing, bonded testing sample will be removed and cooled spontaneously by ambient temperature.

*Table 6 Parameter for post-vulcanization*

Variable	Setpoint
Force	300 kN
DL1 Upper	180 °C
DL1 Lower	180 °C



*Figure 36 Scheme of laboratory bonding*



*Table 7 Positions for laboratory bonding*

Position	Name
1	Warming desks
2	Heated desks
3	Testing sample

Before bonding the surfaces of metallic samples must be activated. As was written in chapter **METAL SURFACE PREPARATION** surfaces on stabilize bars are activated by laser, in our laboratory conditions we used sanding sponge. Thanks to this operation, we extend adhesive surface.

*Figure 37 Surface activating*

After post-vulcanization, bonding testing samples were evaluate decoupling and assess by two conditions which are necessary for researching of quality on the interface connection between rubber-metal. Sheat test and material failure.

Shear test was to wage on the testing device called Instron® 8871

Testing speed for shear strength was set to **0,25 mm/s**. Test ends after decoupling of rubber from metallic parts.

## 8.1 Testing device

Shear testing was conduct on Instron® 8871. This testing systems have been developed to meet the challenging demands of a varied range of both static and dynamic testing requirements. The flexibility offered by 8871 provides complete testing solutions to satisfy the

needs of advanced materials, biomedical and component testing. The compact design of the 8871 frames make them ideal for installation within any laboratory environment, either on an existing bench, or with it is own purpose designed support frame. (27)



*Figure 38 Testing device Instron 8871 (27)*

## 9 INFLUENCE OF COOLING PROCESS FOR BONDING TIME

After discovery of right post-vulcanization time, influence of cooling process will be detected. Process of making of the testing samples is same as before just as devices. Warming of the pressing desks, metallic surface activation, pressing. But, after post-vulcanization testing samples will not be removed from testing mold but will be placed into vessel and cooled by air blows from funnel (by temperature of 20 °C) but without any pressure. After cooling operation testing samples were tested on the same device under same conditions just as was written in chapter 8. **Detection of ideal post-vulcanization time.**

Intensity of air blowing:

- 25 % of opened air tap - calculated to mass flow rate = 0,00043077375 m<sup>3</sup>/s
- 50 % of opened air tap - calculated to mass flow rate = 0,0008615475 m<sup>3</sup>/s
- 75 % of opened air tap - calculated to mass flow rate = 0,00129232125 m<sup>3</sup>/s
- 100 % of opened air tap - calculated to mass flow rate = 0,001723095 m<sup>3</sup>/s

For next testing intensity of air blowing will be indicate by percentages of opened air tap.

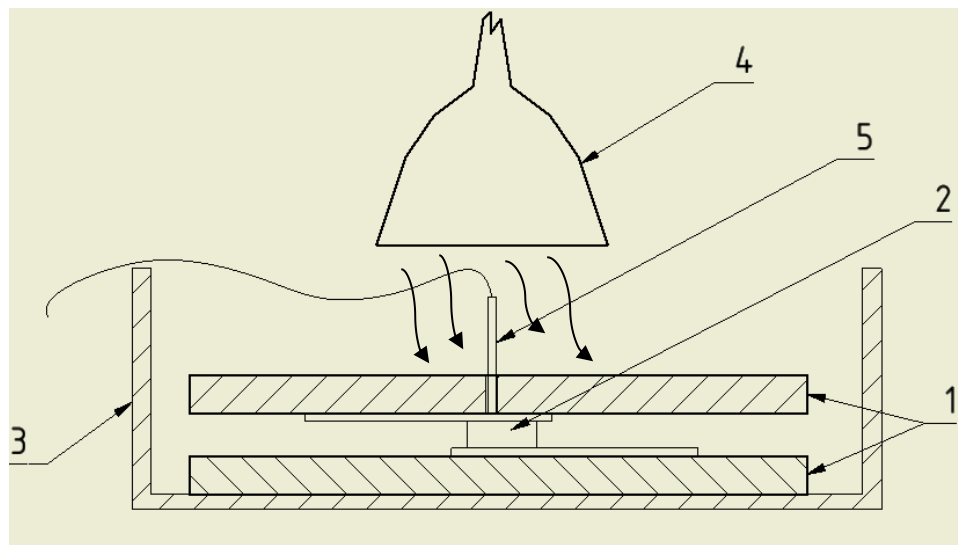


Figure 39 Scheme of cooling process

Table 8 Positions for laboratory cooling

Position	Name
1	Pressing desks
2	Tsting sample
3	Vessel
4	Funnel
5	Temperature detector

## 9.1 Temperature detector

Highly precise digital temperature with external feeding tube which is fixed by one-meter long cable to measure device. This measure device is optimal for using in laboratory.

Gauging range: -50 °C to 270 °C. Accuracy- 0,07 °C

Temperature reading every 15 seconds.



*Figure 40 Temperature detector*

## 10 SHORE A

Shore A testing was used for detection if cooling influences rubber and its mechanical properties or Chemosil on its surface. This was detected thanks to Shore A testing.

Rubber testing sample (without Chemosil on its surface) was pressed in testing mold, then cooled to 60 °C by 100 % air blowing intensity and tested on Shore Durometer. This sample will be compared to sample which is non-cooled.

The testing is subjecting by standard ČSN EN ISO 868.

### Shore durometer hardness testing

The hardness of rubbers is most commonly measured by the Shore Durometer test. This method measures the resistance of rubbers toward indentation and provide an empirical hardness value that doesn't necessarily correlate well to other properties or fundamental characteristics. (28)

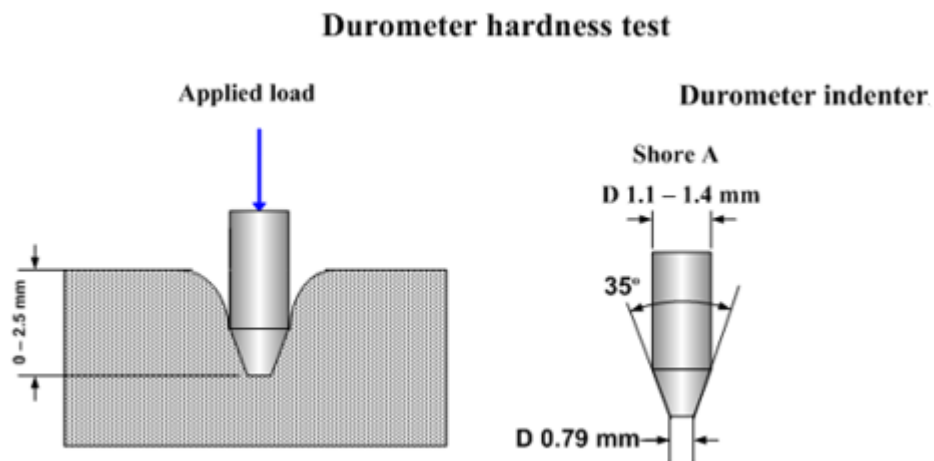


Figure 41 Shore A Durometer principle (28)

### Testing

- Testing sample dimensions: 25 x 25 x 6 mm
- Room temperature 21,8 °C
- Type of durometer: Shore A Durometer
- Applied deformation 15 seconds
- Measures in five different points

## 11 DESIGN OF TESTING MOLD

Four our laboratory testing samples making special testing mold, was designed in Autodesk Inventor 2018 program. This device serves for making test samples by special operation called post-vulcanization and for temperature measuring on the rubber-metallic surface. After design of testing mold the manufacturing drawings were made, which are listed in appendices.

It is consist of lower clamping desk, upper desk, pins, storages and screws which are necessary for required closing strength.

Lower desk, upper desk, storages and pins are made from C45E steel ČSN EN 10083-1 marking (ČSN 12 050)

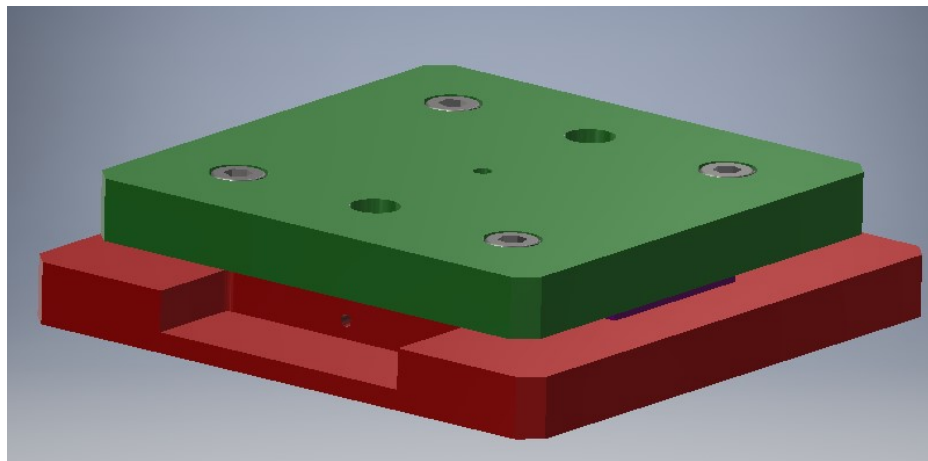


Figure 42 Testing mold in Inventor 2018

Position	Name
1	Lower desk
2	Upper desk
3	Storage
4	Screw
5	Magnet
6	Upper metallic testing sample
7	Lower metallic testing sample
8	Rubber testing sample

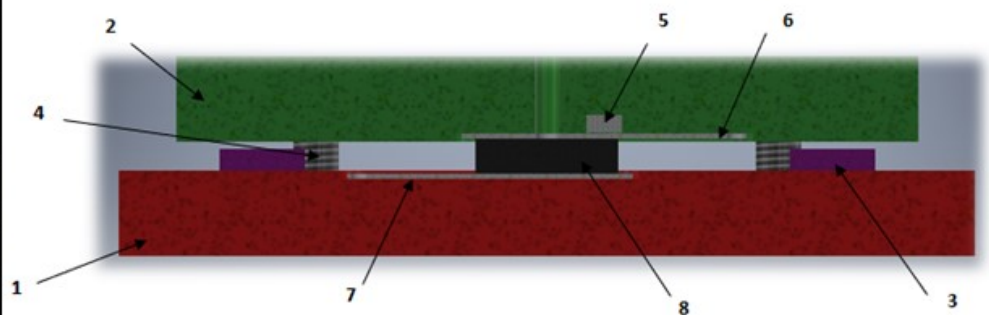


Figure 43 Cut of testing mold in Inventor 2018

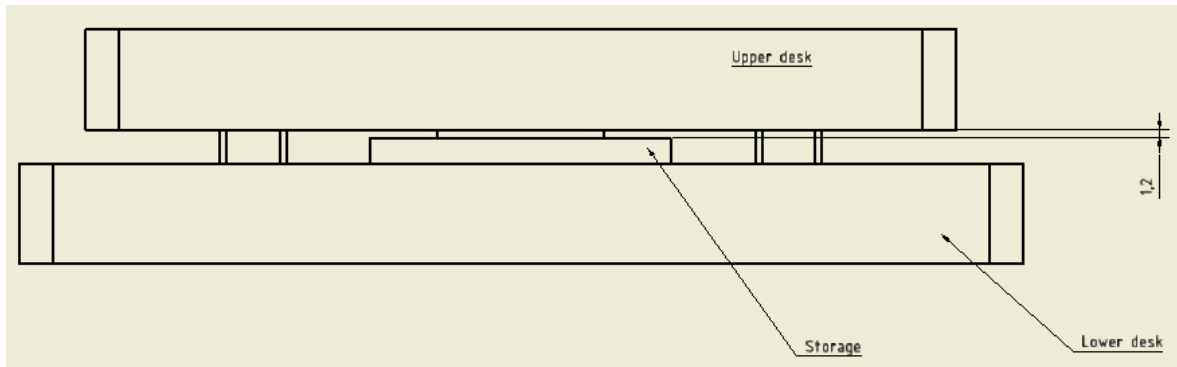


Figure 44 Sketch of testing mold

Space between upper desk and storages is exactly 1,2 mm before weighting (pressing). As was written in chapter **Post-vulcanization** - deformation of the rubber is about 10-20% during compression, this secure adequate contact of the surfaces, supply heat creates strong bond. In our case rubber deformation is 1,2 mm (20 % of rubber deformation)

### 11.1 Lower desk with storages and pins

Lower desk serves for pins fixing which helps us to establish upper desk before mold closing. Further the holes for screws are makes and the storages are fixed with the help of screws.

In the middle of the desk, the pocket is makes by milling operation for the metal testing sample.

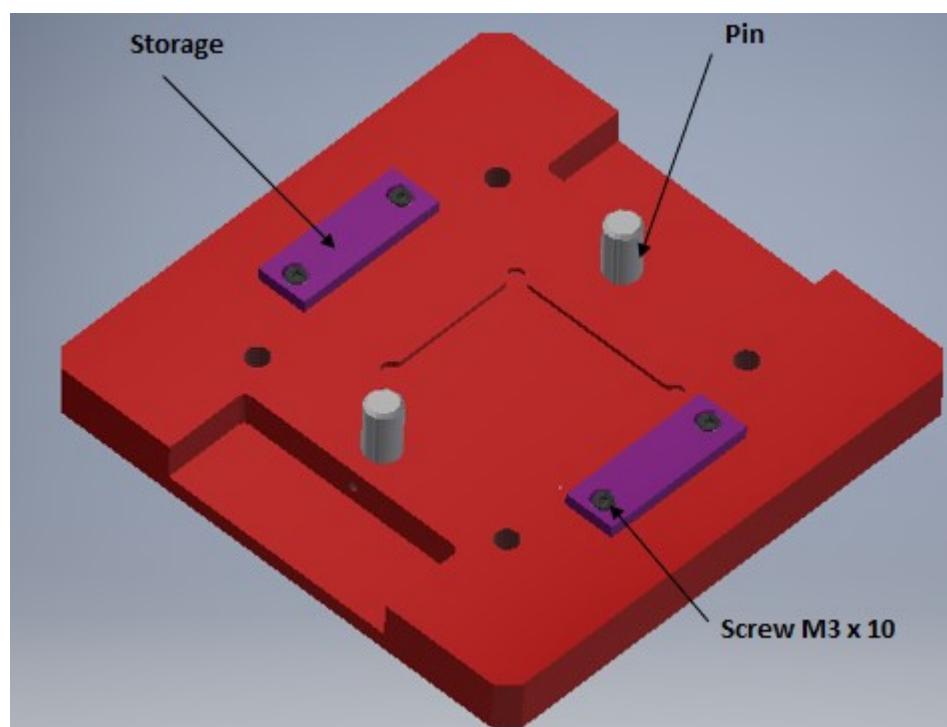
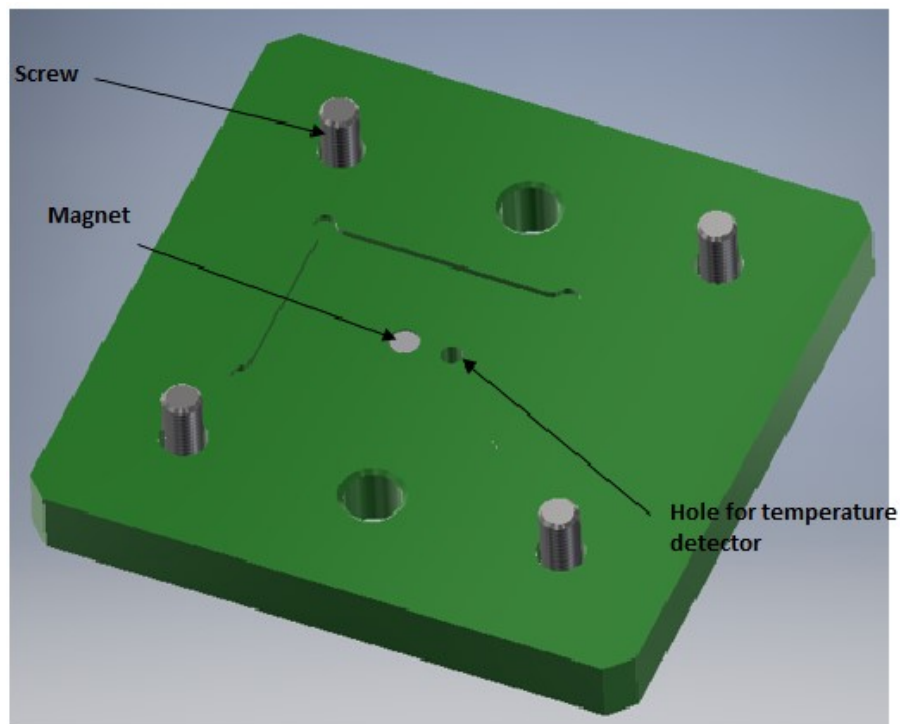


Figure 45 Lower desk

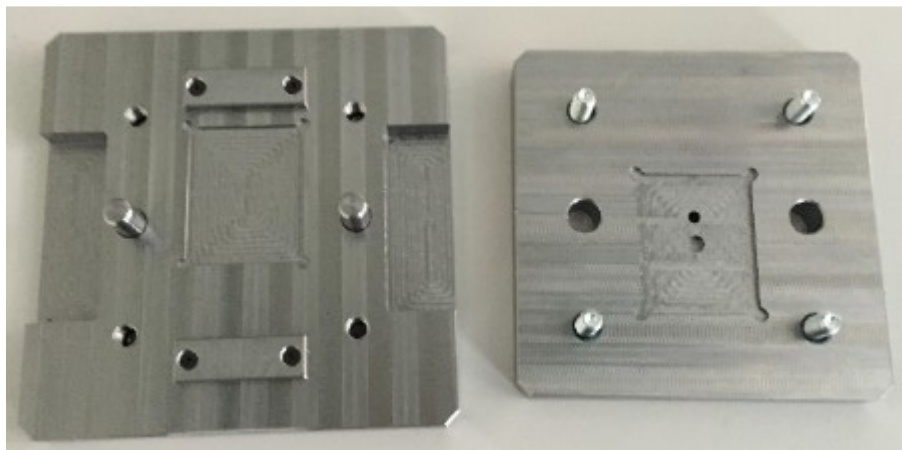
## 11.2 Upper desk with screws and magnet

In the upper desk four screws are placed, these screws connects upper and lower desk and creates necessary strength for bonding between rubber and metallic surfaces.

In the middle of the desk, the pocket is makes by milling operation for the metal testing sample and the pocket for magnet which helps us to keep metallic testing sample to upper desk. Next to pocket for magnet the hole is making. This hole serves for installation of temperature detector.

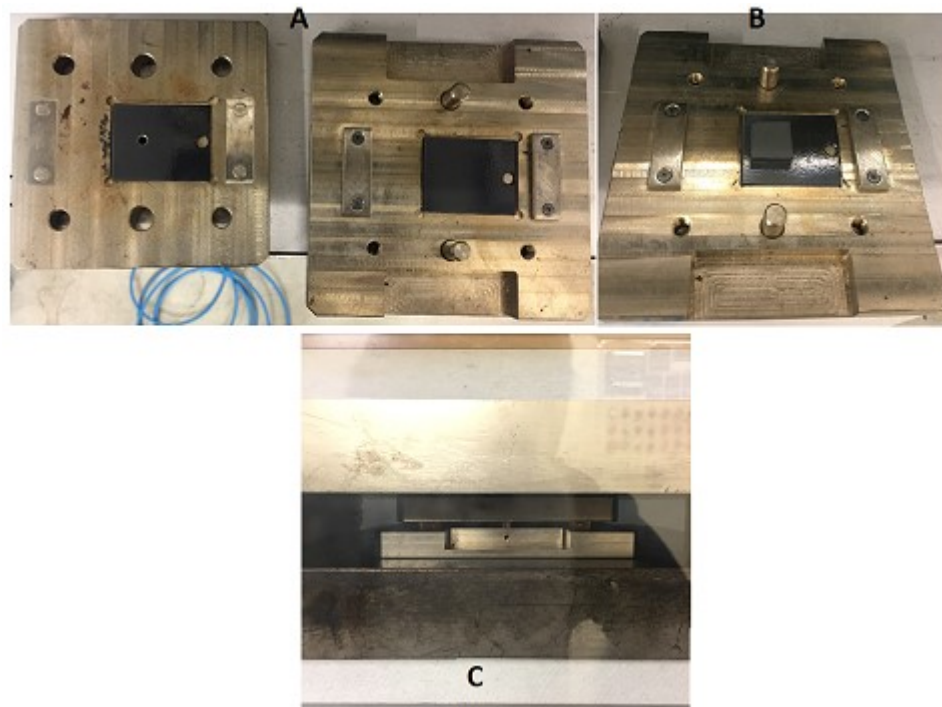


*Figure 46 Upper desk*



*Figure 47 Finished testing mold*





*Figure 48 A- placement of metallic testing samples into the testing mold, B- placement of rubber sample onto lower metallic testing sample, C- pressing*

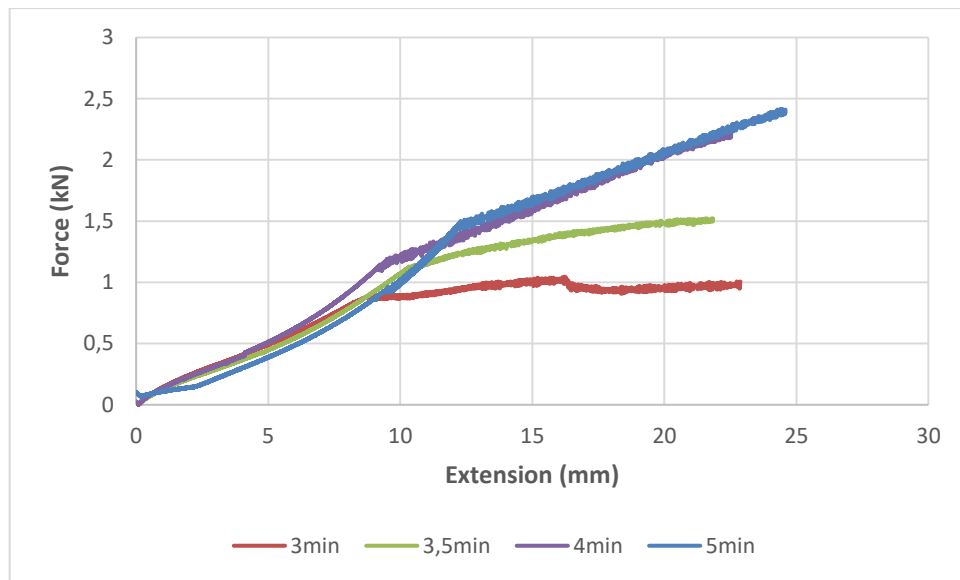


*Figure 49 Cooling of the testing mold and testing sample*

## 12 RESULTS

### 12.1 Determination of optimal bonding time

After bonding, the testing samples were tested on shear testing machine and dependence of force on extension for singles times were compare to each other in *Figure 50*.

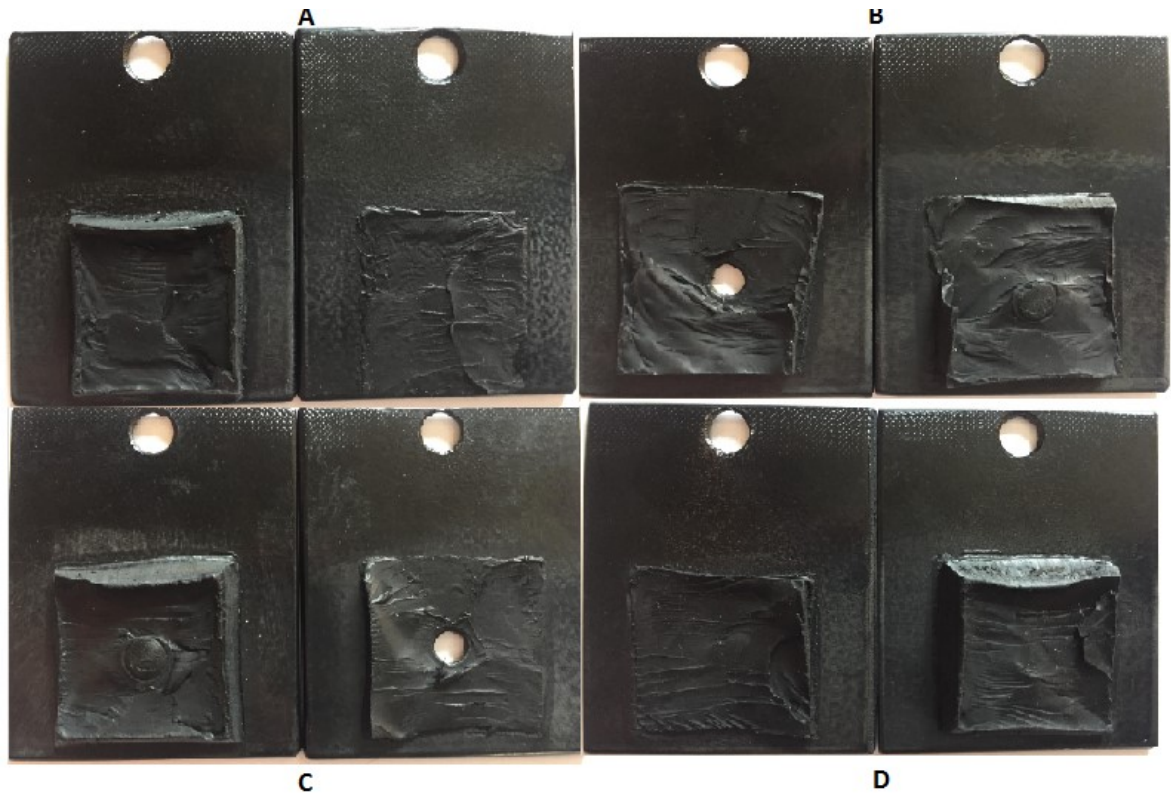


*Figure 50 Dependence of force on extension*

As was expected highest measured load was for testing samples which were pressed for 5 minutes (about 2,4 kN) after that 4 minutes with load about 2,2 kN, followed 3,5 minutes with average 1,5 kN and lowest average force was for 3 minutes pressed samples. Therefore, the higher post-vulcanization time, the higher needed force for decoupling.

Extension for every pressed time samples exceed 20 mm. Lowest can be found for three and half minutes testing samples, that can be caused by polluted or wrong activated metal surfaces.

Other important criterion for plotting how strong bonds are create between rubber and metal is checking material failure as was written in chapter TESTING METHODOLOGY. It is demanded that 90 % of surface must be covered by rubber after tensile testing.



*Figure 51 Testing samples after shear test. A-five minutes post-vulcanized sample, B- four minutes post-vulcanized sample, C- three and half minutes post-vulcanized sample, D- three minutes post-vulcanized sample*

In *Figure 51* is clearly see that only material failure was in rubber- **R** failure. **R**- failure means that rubber tensile strength is smaller, then strength between rubber/cover, cover/primer, cover/metal, that means breaching only in rubber. Post-vulcanized time does not affects rubber adhesion to metallic part. Every tested sample has R-failure exact 100 %.

Last evaluation criterion for plotting testing samples is the amount of adhesion between rubber and metal:

$$Ra = \frac{F_a}{a} [N/mm^2]$$

Where:

- $F_a$ - maximum strength (N)
- $a$ - site of testing sample

Example for average testing sample pressed 3 minutes:

- $F_a$ - maximum strength 1,0001 kN = 1000,1 N
- $a$ - site of testing sample- 20 x 20 mm = 400 mm<sup>2</sup>

$$R_{3 \text{ minutes}} = \frac{F_{3 \text{ minutes}}}{a} = \frac{1000,1}{400} = 2,50025 [N/mm^2]$$

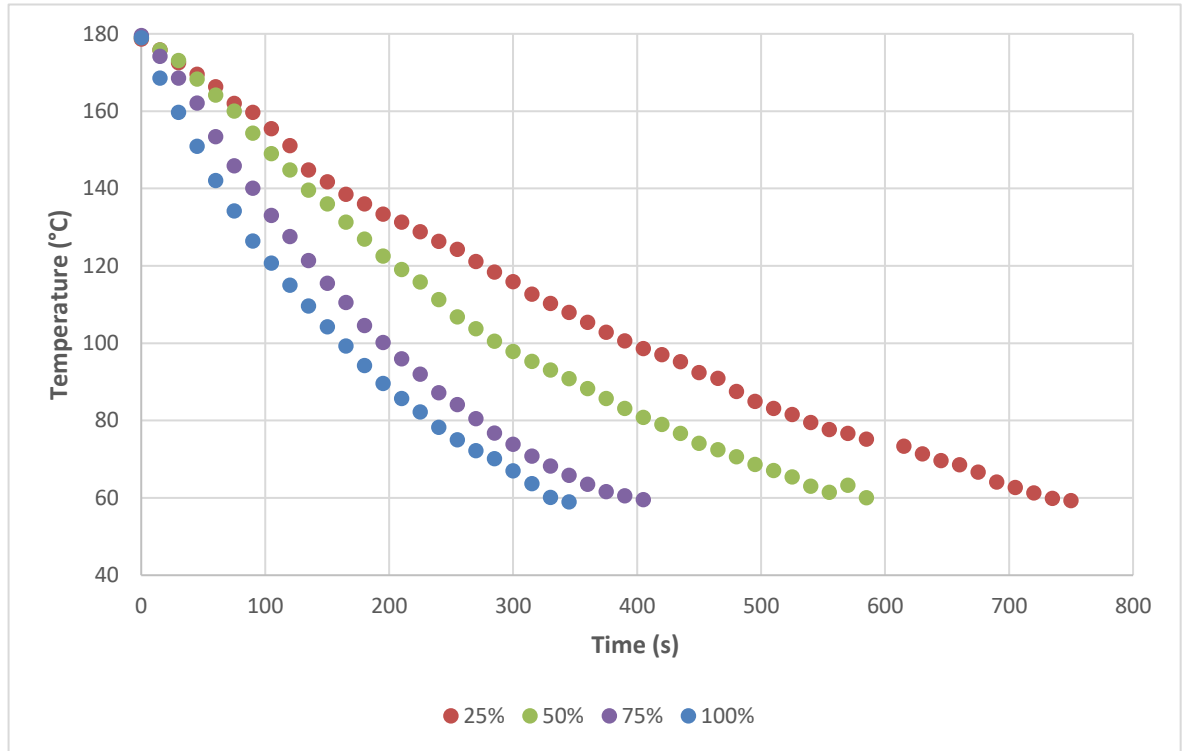
*Table 9 Maximal strength on rupture*

Post-vulcanization time	Maximum strength	Site	Amount of adhesion
(minutes)	(N)	(mm)	(N/mm <sup>2</sup> )
3 minutes	1000,1	400	2,50025
3,5 minutes	1516,1	400	3,79025
4 minutes	2348,4	400	5,87100
5 minutes	2414,8	400	6,03700

Highest amount of adhesion between rubber and metallic samples is for 5 minutes bonded samples just as maximum strength followed by 4 minutes. For that reason for our further testing of the influence of cooling process after rubber post-vulcanization on bonding strength will be used samples which would be pressed for 4 and 5 minutes. This times has just lower variance between them, and to save a minute in business means save a lot of money, it can be found a big import to test it.

## 12.2 Influence of the bonding time on the

### 12.2.1 Five minutes bonding time



*Figure 52 Dependence of temperature on time*

As we can see from the *Figure 52* fastest cooling time was for samples which were cooled by air of intensity 100 % of opened tap. It took average 350 seconds to cooled them to 60 °C temperature on the surface between rubber and metal samples. Followed by intensity of air blowing 75 % o opened tap (400 seconds), 50 % (around 590 seconds) and for 25 % took 780 seconds to cooled post-vulcanized samples on the temperature of 60 °C.

Tables of cooling for every testing sample are listed in appendices.

From *Figure 53*, where cooling and non-cooling samples are compared, is clearly see that cooling of the testing samples does not affected force which is necessary for samples plotting (around 2,2 to 2,5 kN). On second thought it has a big affected on extension of cooling samples, cooling samples has around 10 mm extension lower than non-cooling samples.

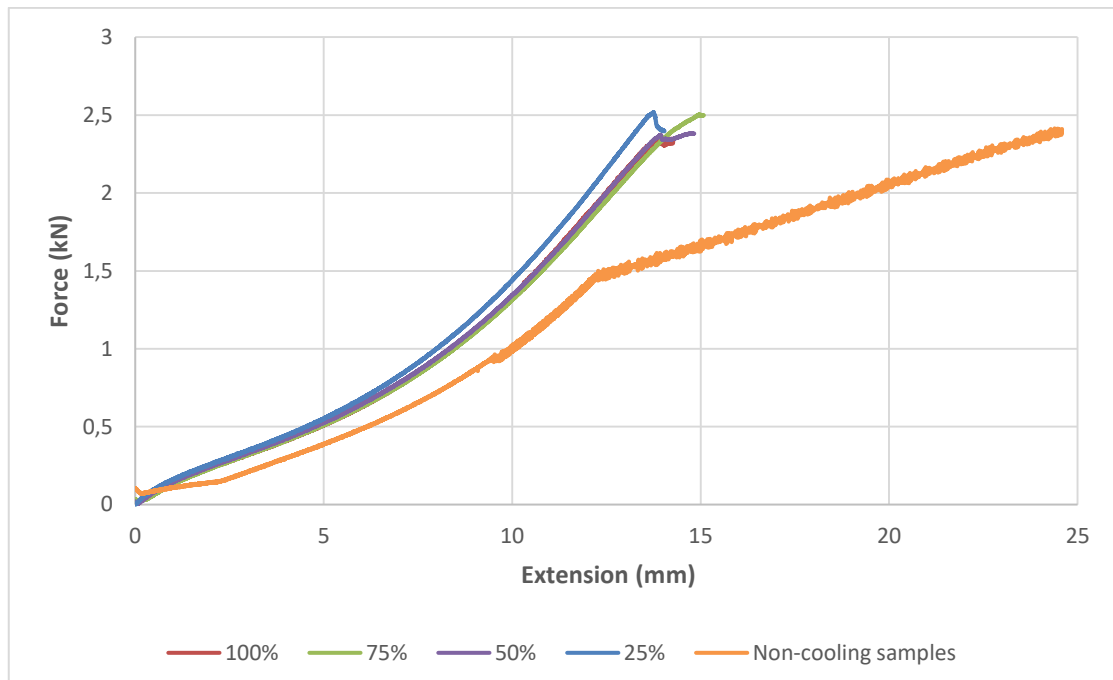


Figure 53 Dependence of force on extension for five minutes pressed samples

### Material failure

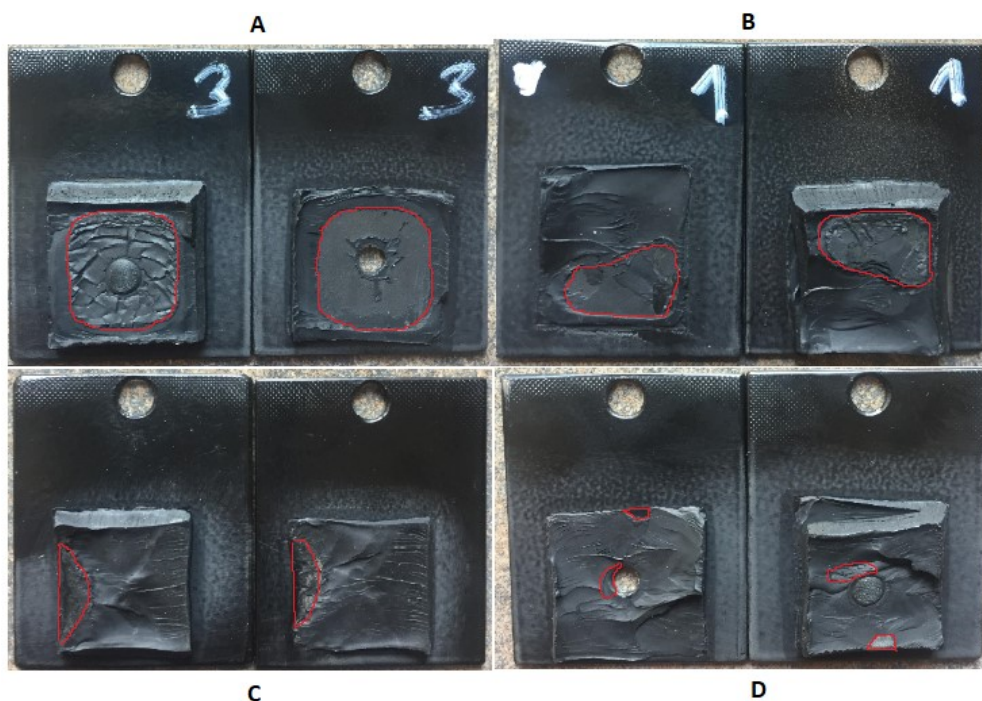


Figure 54 Testing samples after tensile strength test- A- 100% air blowing intensity, B- 75% air blowing intensity, C- 50% air blowing intensity, D- 25% air blowing intensity

In *Figure 54* two failures of material can be seen. **R** failure and **CM** (cover/metal failure, red marked area). **CM**- means failure between cover and metal- weakest point is between metallic part and cover. This failure can be identify by shiny surfaces (on the rubber and metallic surface also). With increasing intensity of air blowing percentages **CM** failure rises and **R** failure decline. For testing samples, **A**, **B** and **C** coating from metallic part was pull off.

As can be seen in *Figure 54* **CM** material failure grows with cooling intensity. In this case percentages of **CM** failure on our testing samples are more than 80 % **A** sample, 35% (**B** sample), 12% (**C** sample) and around 5% on the **D** sample.

As was written chapter above it is demanded that 90 % of surface must be covered by rubber after shear testing. Samples with air blowing intensity 50, 75 and 100 % does not comply.

**Amount of adhesion**

**Amount of adhesion between rubber and metal:**

$$Ra = \frac{F_a}{a} [N/mm^2]$$

Where:

- $F_a$ - maximum strength (N)
- $a$ - site of testing sample

Example for average testing sample cooled 50% of intensity air blowing:

- $F_a$ - maximum strength 2,379874 kN = 2379,874 N
- $a$ - site of testing sample- 20 x 20 mm = 400 mm<sup>2</sup>

$$R_{50\%} = \frac{F_{50\%}}{a} = \frac{2379,874}{400} = 5,9496 [N/mm^2]$$

*Table 10 Maximal strength on rupture for different cooling intensity*

Post-vulcanization time	Intensity of cooling	Maximum strenght	Site	Amount of adhesion
(minutes)	%	(N)	(mm <sup>2</sup> )	(N/mm <sup>2</sup> )
5 minutes	25	2254,464	400	5,636
	50	2379,874	400	5,950
	75	2498,822	400	6,247
	100	2324,845	400	5,812

As can be seen from Figure 52 air cooling does not affected maximal strength and so as amount of adhesion between rubber and metallic samples. It is from 5,6 to 6,2 N/mm<sup>2</sup> and compared to non-cooling samples where average amount of adhesion was 6,03 N/mm<sup>2</sup>, cooling samples has basically same value. But its radically changed adhesion between rubber and metal surface. With higher intensity of air cooling, **R - failure** decline to almost only 20 % while **CM failure** grows to a point where metal coating was pulled of testing samples.

### 12.2.2 Four minutes bonding time

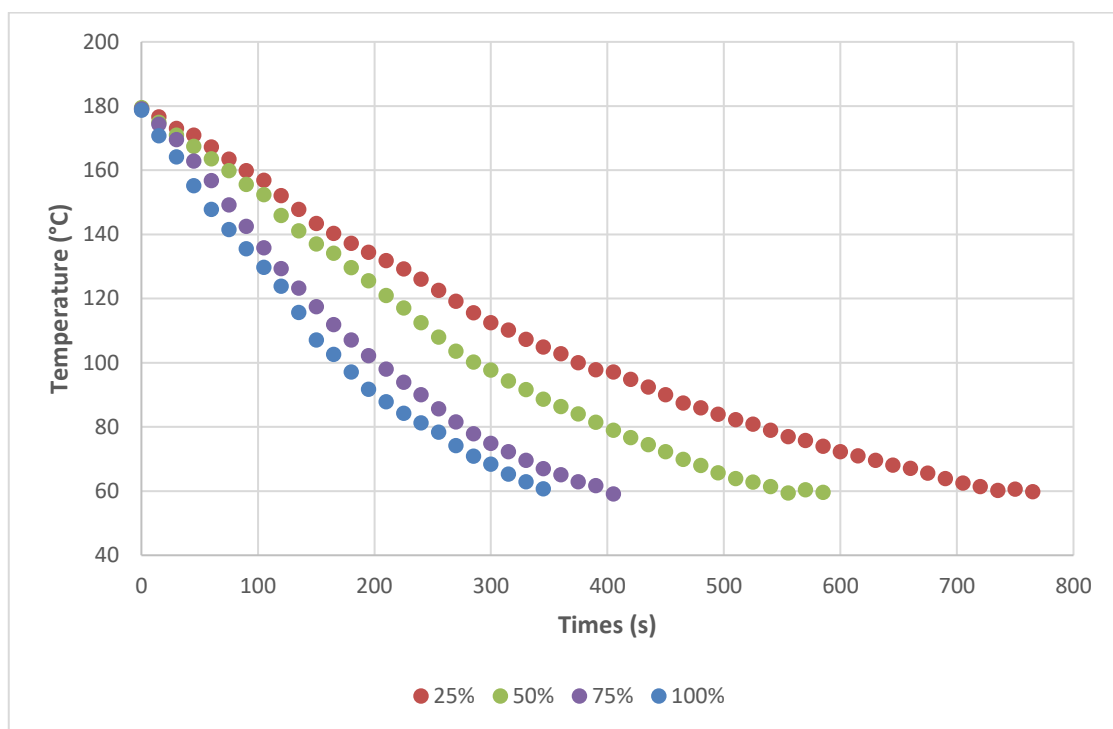


Figure 55 Dependence of temperature on time

Just as in chapter **Results for 5 minutes bonding time** fastest average time was for samples which were cooled of 100% intensity of air blowing which it takes about 350 seconds. Slowest cooling time was for 25% air blowing intensity.

Tables of cooling for every testing sample are listed in appendices.

From *Figure 56*, where cooling and non-cooling samples are compared, is clearly see that cooling of the testing samples does not affected on the force which is necessary for samples plotting (around 2,1 to 2,3 kN). On second thought it has a big affected on extension of cooling samples, cooling samples has around 10 mm extension lower than non-cooling samples.



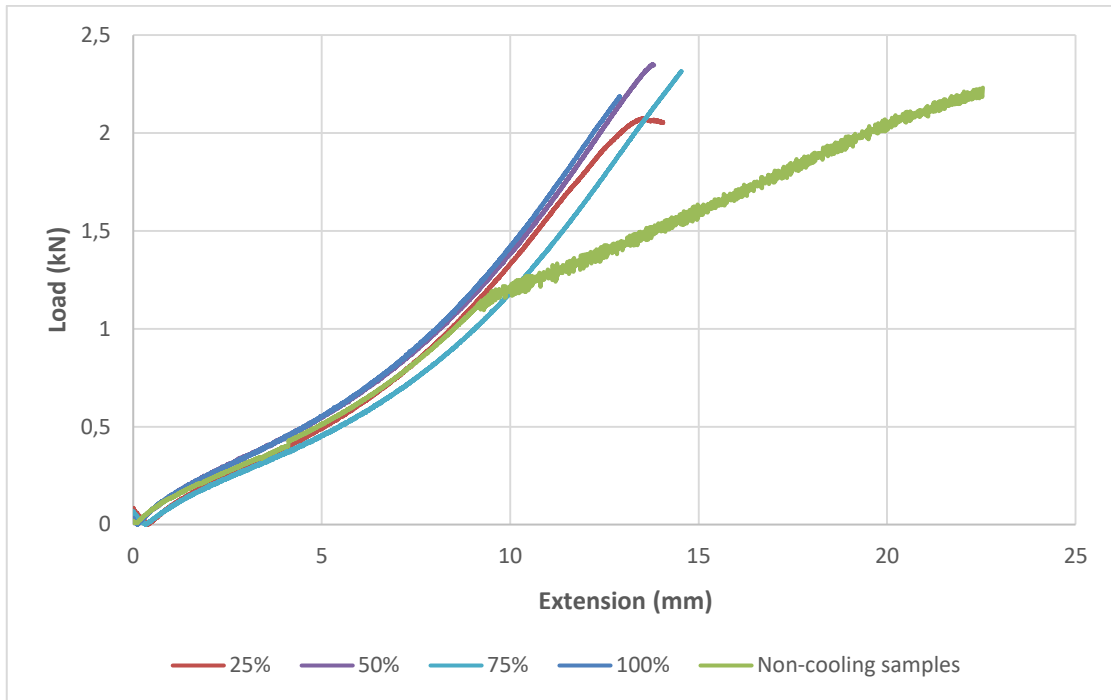


Figure 56 Average four minutes bonding times for different cooling intensity

**Material failure**

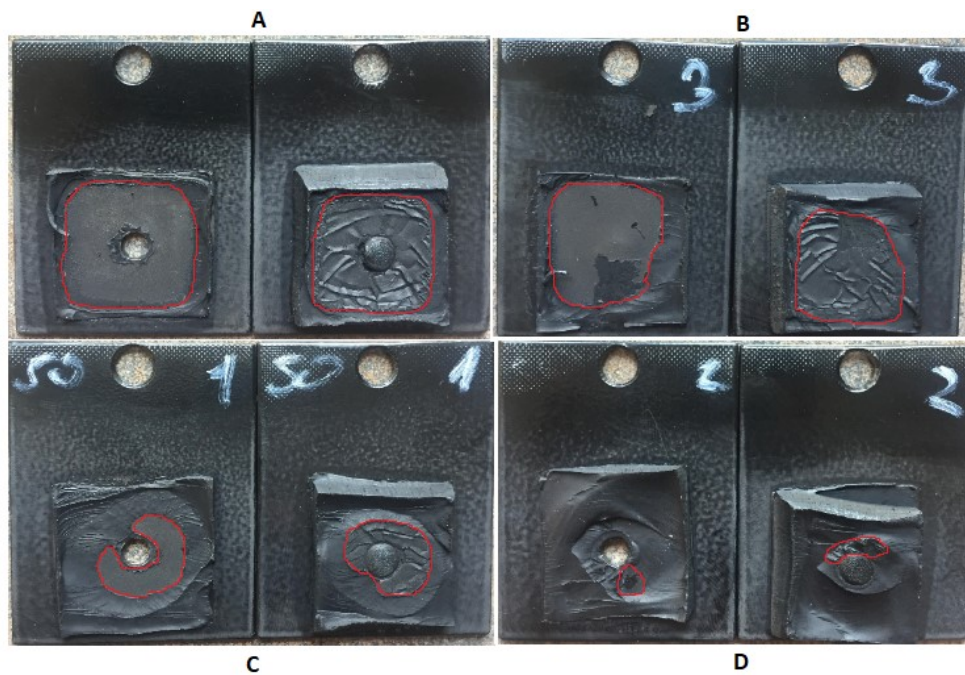


Figure 57 Figure 51 Testing samples after tensile strength test- A- 100% air blowing intensity, B- 75% air blowing intensity, C- 50% air blowing intensity, D- 25% air blowing intensity

In Figure 57 two failures of material can be seen. **R** failure and **CM** (cover/metal failure, red marked area). This failure can be identify by shiny surfaces (on the rubber and metallic

surface also). With increasing intensity of air blowing percentages **CM** failure rises and **R** failure decline. At testing samples **A**, **B** and **C** coating from metallic part was pull off.

As can be seen in *Figure 56* **CM** material failure grows with cooling intensity. In this case percentages of **CM** failure on our testing samples are more than 80 % **A** sample, 60% (**B** sample), 15% (**C** sample) and around 5% on the **D** sample.

As was written chapter above it is demanded that 90 % of surface must be covered by rubber after tensile testing. Samples with air blowing intensity 50, 75 and 100 % does not comply.

### Amount of adhesion

#### Amount of adhesion between rubber and metal:

$$Ra = \frac{F_a}{a} [N/mm^2]$$

Where:

- $F_a$ - maximum strength (N)
- $a$ - site of testing sample

Example for average testing sample cooled 75% of intensity air blowing:

- $F_a$ - maximum strength 2,3144 kN = 2314,4517 N
- $a$ - site of testing sample- 20 x 20 mm = 400 mm<sup>2</sup>

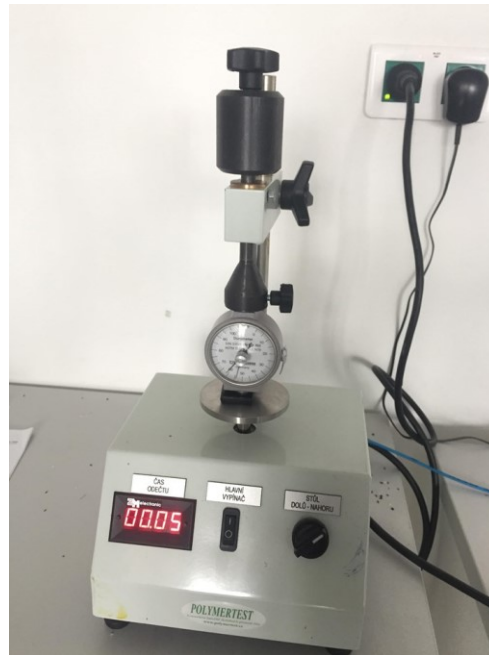
$$R_{75\%} = \frac{F_{75\%}}{a} = \frac{2314,4517}{400} = 5,7861 [N/mm^2]$$

*Table 11 Maximal strength on rupture for different cooling intensity*

Post-vulcanization time	Intensity of cooling	Maximum strenght	Site	Amount of adhesion
(minutes)	%	(N)	(mm)	(N/mm <sup>2</sup> )
4 minutes	25	2185,1952	400	5,4629
	50	2397,3445	400	5,9933
	75	2314,4517	400	5,7861
	100	2102,5898	400	5,2564

### 12.3 Shore A

From previous chapters and results it is clearly obvious that cooling has a big influence onto extension and material failure. But what we did not know is if cooling influences rubber or adhesive product applied on its surface. That will be detected thanks to Shore A Durometer.



*Figure 58 Shore A Durometer*

#### Testing

- Testing sample dimensions: 25 x 25 x 6 mm
- Room temperature 21,8 °C
- Type of durometer: Shore A Durometer
- Applied deformation 15 seconds
- Measures in five different points

*Table 12 Results of Shore A testing for cooling sample*

	Type	Time of applied force (s)	Hardness
1	Shore A	15	54
2			53,5
3			54,5
4			53
5			55
		<b>Average hardness</b>	54

*Table 13 Results of Shore A testing for non-cooling sample*

	Type	Time of applied force (s)	Hardness
1	Shore A	15	54
2			53,5
3			54,5
4			55
5			53
		<b>Average hardness</b>	54

Enrolment for cooling sample by standard ČSN EN ISO 868: **Shore A/15:54**

Enrolment for non-cooling sample by standard ČSN EN ISO 868: **Shore A/15:54**

Thanks to Shore A testing, was find out that cooling by air does not affected rubber and its properties. Measured hardness was same as for cooling and for non-cooling sample. It is clearly see that cooling influences joining between rubber and metal.

## CONCLUSION

In theoretical part of master's thesis was described procedure of bonding rubber bushing parts onto stabilizer bars and that was transform into laboratory conditions. Whole process of making testing samples was describe from detection of rheological properties to vulcanization of rubber plates. From these plates rubber testing samples was made by dimensions 20 x 20 x 6 mm and by priming operation special bonding adhesive medium was applied on its surface.

For transform of manufacturing process into the laboratory conditions was used design testing mold were testing samples were bonded by according to acquired knowledges. Post - vulcanization was to wage on Hydraulic presser FONTIJNE PRESSES LabEcon 300. Thanks to this preparation optimal post-vulcanization time was found by tension test.

Plotting of testing samples was subject on three criterions. Highest force and extension, material failure and amount of adhesion between rubber and metal. For all tested times rubber failure **R** was detected 100 % and it was clearly seen that post-vulcanization time does not influence failure in material. However, five minutes and four minutes testing samples highest needed strength for their breaching, longest extension and highest amount of adhesion compare to others. Therefore, samples with four and five minutes were chosen to our next texting of influence of cooling.

The main goal of presented master's thesis was to evaluate influence of cooling for rubber metal bonding and to asses quality of bonding for different intensity of air cooling of temperature 20 °C. Samples which were bonded for four and five minutes were cooled by air of four different intensities. This cooling was to wage in aluminum vessel and testing samples with testing mold was cooled from the top to the temperature of 60 °C on the surface rubber metal. This temperature was detected by temperature detector established thru the hole in testing mold and in metallic testing sample.

Testing samples were tested on the Instron® 8871 device. After testing it was established that cooling has enormous influence to the bonding surface. With increasing intensity of blowing, increased **CM** material failure which is failure between cover and metal. With highest blowing intensity **CM** failure was almost 80 % and that was detected for both cases (four, and five minutes bonding). In some cases metallic coat was damaged.

Also cooling samples has lower extension. That difference was 10 mm compared to non-cooled samples. Also, must be told that cooling does not influences needed strength and amount of adhesion between rubber and metal. Compared to non-cooling samples these values were similar.

Last testing was hardness by Shore A durometer. In this case, hardness of cooling and non-cooling samples were compared. Hardness of cooling and non-cooling samples were same and thanks to this it can be told that cooling does not influence rubber and its mechanical properties but it influences special bonding adhesive medium which creates bonds between rubber and metal.

Acquired results shows that cooling definitely speed up production but to the expense of lower adhesion between rubber-metal surface. In view of that, cooling by air is not required for post-vulcanization operation, however cooling by other medium would to have a purpose to tested.

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**LIST OF ABBREVIATIONS**

phr	Parts per hundred rubber
NR	Natural rubber
SBR	Styren-butadiene rubber
°C	Degree of centigrade
BR	Butadiene rubber
µm	Mikro meter
PV	Post-vulcanization
kV	Kilo - Volt
R	Rubber failure
RC	Rubber/cover failure
CP	Cover/primer failure
F <sub>b</sub>	Maximum strenght for peel test
b	Width of testing sample
R <sub>b</sub>	Amount of adhesion for peel test
R <sub>a</sub>	Amount of adhesion for tension test
F <sub>a</sub>	Maximum strength for tension test
a	Site of testing sample
N/mm <sup>2</sup>	Newton per square milimeter
mm	milimeter
N	Newton unit
M <sub>m</sub>	Minimal torgue
M <sub>H</sub>	Maximal torgue
t <sub>50</sub>	50 % vulcanized rubber
t <sub>70</sub>	70 % vulcanized rubber

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$t_{90}$	90% vulcanized rubber
dNm	Deci-Newton meter
kN	Kilo-Newton
mm/s	Milimeter per second
s	second
$\sigma$	stress
$\varepsilon$	strain
$\Delta l$	amount by which the length of the object changes
$l$	length
$l_0$	Original length
E	Young modulus

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## APPENDICES

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**APPENDIX P I: TABLE OF COOLING TIME FOR 25 % OF AIR  
BLOWING INTENSITY (5 MINUTES)**

	25 %			
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	178,54	179,09	178,32	178,65
15	175,21	176,32	176,02	175,85
30	171,61	172,01	174,11	172,58
45	166,95	169,50	172,20	169,55
60	162,20	167,55	169,36	166,37
75	159,61	162,62	163,90	162,04
90	157,91	161,01	160,21	159,71
105	153,41	155,14	157,88	155,48
120	150,99	149,96	152,32	151,09
135	147,45	141,61	145,45	144,84
150	144,49	137,90	142,86	141,75
165	141,91	134,10	139,57	138,53
180	139,60	130,74	137,73	136,02
195	137,54	127,56	135,09	133,40
210	135,46	124,97	133,49	131,31
225	134,19	121,29	131,03	128,84
240	132,36	118,57	128,31	126,41
255	130,21	116,67	125,98	124,29
270	128,10	113,42	121,97	121,16
285	125,99	110,13	119,12	118,41
300	121,62	108,93	117,32	115,96
315	118,45	105,68	114,01	112,71
330	115,93	103,20	111,86	110,33
345	113,98	100,70	109,32	108,00
360	111,03	98,45	106,80	105,43
375	109,20	95,75	103,73	102,89
390	107,47	93,17	101,21	100,62
405	105,38	91,17	99,37	98,64
420	104,25	89,73	97,37	97,12
435	102,93	87,84	94,96	95,24
450	101,51	85,98	89,74	92,41
465	100,11	83,97	88,75	90,94
480	95,10	80,42	87,09	87,54
495	90,99	78,59	85,49	85,02
510	88,53	77,03	83,84	83,13
525	86,97	75,55	82,30	81,61
540	83,87	74,39	80,40	79,55
555	80,64	73,70	78,74	77,69

570	79,72	72,97	77,33	76,67
585	77,91	71,72	76,06	75,23
615	74,80	70,65	74,77	73,41
630	71,17	69,53	73,54	71,41
645	68,29	68,44	72,40	69,71
660	66,85	67,25	71,77	68,62
675	63,99	66,17	69,89	66,68
690	62,55	63,49	66,45	64,16
705	61,42	62,38	64,31	62,70
720	60,29	61,33	62,23	61,28
735	59,65	59,88	60,21	59,91
750	-	-	59,31	59,31

**APPENDIX P II: TABLE OF COOLING TIME FOR 25 % OF AIR  
BLOWING INTENSITY (5 MINUTES)**

	50%			
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	180,01	177,90	179,51	179,14
15	178,32	175,11	174,12	175,85
30	175,20	173,32	171,02	173,18
45	169,23	167,77	167,94	168,31
60	166,90	162,22	163,55	164,22
75	162,16	159,63	158,36	160,05
90	157,70	153,28	152,14	154,37
105	152,12	148,32	146,78	149,07
120	149,85	143,49	141,26	144,87
135	145,31	137,54	136,01	139,62
150	141,71	133,72	132,64	136,02
165	137,76	128,88	127,30	131,31
180	134,32	123,72	122,80	126,95
195	130,58	119,05	118,11	122,58
210	126,97	114,14	116,05	119,05
225	122,44	111,93	113,10	115,82
240	117,07	107,56	109,28	111,30
255	111,83	103,29	105,47	106,86
270	108,01	101,47	101,76	103,75
285	105,64	98,02	98,11	100,59
300	103,06	95,82	94,79	97,89
315	100,48	93,88	91,73	95,36
330	97,95	92,23	89,06	93,08
345	95,62	90,53	86,34	90,83
360	93,36	87,69	83,84	88,30
375	91,15	84,78	81,39	85,77
390	88,93	81,81	78,87	83,20
405	86,76	79,09	76,68	80,84
420	84,80	77,76	74,53	79,03
435	82,87	74,92	72,41	76,73
450	80,83	71,46	70,25	74,18
465	78,82	70,04	68,56	72,47
480	76,48	68,72	66,76	70,65
495	74,51	66,63	64,90	68,68
510	72,61	65,52	63,30	67,14
525	70,85	63,59	61,98	65,47
540	67,49	61,51	60,25	63,08
555	65,75	59,04	59,66	61,48

570	63,27	-	-	63,27
585	60,05	-	-	60,05

**APPENDIX P III: TABLE OF COOLING TIME FOR 75 % OF AIR  
BLOWING INTENSITY (5 MINUTES)**

	75%			
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	179,86	179,91	178,97	179,58
15	175,32	174,26	173,11	174,23
30	170,25	168,83	166,64	168,57
45	164,44	160,09	161,75	162,09
60	158,45	153,18	148,71	153,45
75	152,03	146,56	139,15	145,91
90	144,44	139,96	136,00	140,13
105	136,67	133,29	129,26	133,07
120	132,10	126,74	124,03	127,62
135	125,17	120,34	118,66	121,39
150	118,54	114,62	113,38	115,51
165	112,84	110,62	108,26	110,57
180	108,04	102,70	103,16	104,63
195	103,90	98,17	98,68	100,25
210	99,70	93,76	94,59	96,02
225	95,73	89,66	90,73	92,04
240	91,84	82,59	87,26	87,23
255	88,35	79,80	84,30	84,15
270	84,61	76,25	80,80	80,55
285	80,42	73,17	76,87	76,82
300	77,28	70,99	73,33	73,87
315	74,74	67,67	70,14	70,85
330	72,16	64,83	67,92	68,30
345	69,36	62,50	65,85	65,90
360	66,38	60,24	64,02	63,55
375	64,76	58,15	62,04	61,65
390	61,49		59,68	60,59
405	59,59			59,59

**APPENDIX P IV: TABLE OF COOLING TIME FOR 100 % OF AIR  
BLOWING INTENSITY (5 MINUTES)**

	100%			
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	178,58	179,54	178,94	179,02
15	170,20	167,74	167,79	168,58
30	162,36	159,33	157,59	159,76
45	152,20	149,30	151,47	150,99
60	141,33	138,98	145,89	142,07
75	131,94	131,50	139,34	134,26
90	124,26	124,26	130,81	126,44
105	117,66	118,62	125,84	120,71
120	112,55	112,40	120,14	115,03
135	107,54	106,05	115,37	109,65
150	102,45	100,33	110,02	104,27
165	97,73	95,66	104,61	99,33
180	92,87	91,45	98,49	94,27
195	88,52	87,73	92,64	89,63
210	84,43	84,57	88,31	85,77
225	81,31	80,60	84,88	82,26
240	78,53	77,09	79,30	78,31
255	75,06	73,85	76,38	75,10
270	73,13	70,84	72,81	72,26
285	71,47	68,76	70,40	70,21
300	68,26	64,52	68,36	67,05
315	64,69	62,55	63,92	63,72
330	59,97	59,26	61,14	60,12
345			58,98	58,98

**APPENDIX P V: TABLE OF COOLING TIME FOR 25 % OF AIR  
BLOWING INTENSITY (4 MINUTES)**

25%				
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	179,15	178,98	179,13	179,09
15	176,09	175,88	177,90	176,62
30	172,34	171,67	175,11	173,04
45	170,32	169,07	173,32	170,90
60	168,96	165,04	167,77	167,26
75	166,90	161,04	162,22	163,39
90	162,58	157,20	159,63	159,80
105	159,60	153,01	157,91	156,84
120	153,62	148,99	153,41	152,01
135	147,04	145,30	150,99	147,78
150	141,27	141,48	147,45	143,40
165	138,52	137,71	144,49	140,24
180	135,73	134,01	141,91	137,22
195	132,95	130,67	139,60	134,41
210	130,21	127,62	137,54	131,79
225	127,57	124,70	135,46	129,24
240	124,99	121,68	131,25	125,97
255	121,62	118,41	127,48	122,50
270	117,96	114,84	124,65	119,15
285	114,85	111,67	120,12	115,55
300	113,76	109,04	114,65	112,48
315	111,67	106,94	111,95	110,19
330	109,36	104,84	107,45	107,22
345	107,56	102,93	104,12	104,87
360	105,74	101,15	101,28	102,72
375	102,29	99,26	98,45	100,00
390	100,29	97,23	95,73	97,75
405	98,94	95,16	97,21	97,10
420	95,74	93,17	95,37	94,76
435	92,55	91,28	93,37	92,40
450	89,67	89,44	90,96	90,02
465	86,92	87,61	87,74	87,42
480	85,03	85,85	86,75	85,88
495	83,36	84,22	84,09	83,89
510	81,65	82,56	82,49	82,23
525	80,80	80,79	80,84	80,81
540	79,48	78,85	78,40	78,91
555	77,06	77,25	76,40	76,90

570	75,65	75,80	75,74	75,73
585	74,22	74,30	73,33	73,95
600	72,80	72,87	71,06	72,24
615	71,43	71,50	69,77	70,90
630	69,93	70,13	68,54	69,53
645	68,46	68,80	67,04	68,10
660	67,01	67,56	66,52	67,03
675	65,71	66,06	64,91	65,56
690	64,55	64,82	62,23	63,87
705	62,20	63,76	61,31	62,42
720	60,87	62,28	60,84	61,33
735	59,77	61,63	59,12	60,17
750	-	60,59		60,59
765	-	59,80	-	59,80



**APPENDIX P VI: TABLE OF COOLING TIME FOR 50 % OF AIR BLOWING INTENSITY (4 MINUTES)**

	50%			
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	178,88	180,12	179,59	179,53
15	173,95	175,64	175,21	174,93
30	170,07	171,41	171,34	170,94
45	166,36	167,88	168,02	167,42
60	162,20	163,47	164,87	163,51
75	158,56	159,52	161,48	159,85
90	154,34	155,65	156,59	155,53
105	152,41	153,42	151,33	152,39
120	146,99	144,62	145,98	145,86
135	142,09	139,80	141,33	141,07
150	137,79	135,28	137,85	136,97
165	134,04	132,24	135,89	134,06
180	129,85	127,03	131,94	129,61
195	124,70	122,89	128,88	125,49
210	119,76	118,90	124,01	120,89
225	115,16	116,81	119,24	117,07
240	110,85	112,19	114,16	112,40
255	107,14	107,83	108,79	107,92
270	103,58	103,94	103,26	103,59
285	100,01	100,25	100,14	100,13
300	96,82	97,43	98,67	97,64
315	93,89	94,93	94,16	94,33
330	91,15	92,19	91,53	91,62
345	88,26	90,08	87,53	88,62
360	85,60	87,85	85,57	86,34
375	83,21	85,68	83,29	84,06
390	81,14	82,25	81,02	81,47
405	79,21	79,40	78,25	78,95
420	77,27	76,64	76,13	76,68
435	75,31	74,05	73,88	74,41
450	73,32	71,83	71,71	72,29
465	71,44	69,77	68,48	69,90
480	69,82	67,73	66,31	67,95
495	66,85	65,82	64,36	65,68
510	65,46	63,96	62,14	63,85
525	64,15	62,33	61,87	62,78
540	62,84	60,86	60,47	61,39

555	61,50	58,65	57,98	59,38
570	60,34	-	-	60,34
585	59,59	-	-	59,59

**APPENDIX P VII: TABLE OF COOLING TIME FOR 75 % OF AIR  
BLOWING INTENSITY (4 MINUTES)**

75%				
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	179,47	178,81	179,09	179,12
15	174,95	173,90	174,15	174,33
30	169,10	170,02	169,32	169,48
45	155,79	167,76	165,02	162,86
60	148,33	159,66	162,34	156,78
75	141,92	150,32	155,22	149,15
90	135,86	143,31	148,31	142,49
105	129,43	135,95	141,97	135,78
120	123,28	128,91	135,81	129,33
135	117,15	122,48	130,00	123,21
150	111,65	116,37	124,28	117,43
165	106,64	110,74	118,09	111,82
180	101,58	106,87	112,81	107,09
195	96,87	101,23	108,56	102,22
210	92,99	96,54	104,45	97,99
225	89,08	92,40	100,34	93,94
240	84,64	88,45	96,86	89,98
255	78,38	84,97	93,50	85,62
270	75,03	81,70	87,97	81,57
285	70,96	79,52	83,05	77,84
300	68,17	76,80	79,62	74,86
315	65,66	73,73	77,22	72,20
330	63,83	71,18	73,53	69,51
345	61,45	68,93	70,49	66,96
360	60,45	66,98	67,69	65,04
375	59,52	63,98	65,16	62,89
390		60,33	62,95	61,64
405		58,21	59,89	59,05

**APPENDIX P VIII: TABLE OF COOLING TIME FOR 100 % OF AIR  
BLOWING INTENSITY (4 MINUTES)**

100%				
	Testing sample 1	Testing sample 2	Testing sample 3	
Time (s)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average temperature
0	178,24	179,77	177,90	178,64
15	172,65	170,15	169,35	170,72
30	164,17	166,80	161,35	164,11
45	152,05	158,86	154,37	155,09
60	144,54	152,49	146,35	147,79
75	139,26	145,76	139,43	141,48
90	133,90	139,17	133,28	135,45
105	128,80	132,77	127,57	129,71
120	123,69	126,32	121,45	123,82
135	114,67	116,45	115,71	115,61
150	106,38	104,61	110,32	107,10
165	102,56	99,62	105,49	102,56
180	95,50	95,59	100,28	97,12
195	89,31	90,91	94,94	91,72
210	85,73	87,34	90,35	87,81
225	82,33	83,68	86,73	84,25
240	79,41	80,55	83,62	81,19
255	76,68	77,96	80,46	78,37
270	71,90	73,15	77,25	74,10
285	67,45	70,94	74,07	70,82
300	65,36	68,34	71,24	68,31
315	63,53	63,65	68,63	65,27
330	61,78	61,20	65,71	62,90
345	60,00	59,16	62,97	60,71
375			59,79	