KAUNAS UNIVERSITY OF TECHNOLOGY
Faculty of Mechanical Engineering and Design

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Investigation of Mechanical Properties of Furniture Springs and Development of their Heat Treatment Technology

Master's Degree Final Project

Supervisor
Assoc. Prof. Dr. Rasa Kandrotaitė Janutienė

KAUNAS, 2017

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Master's Degree Final Project
Mechanical Engineering (621H30001)

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KAUNAS UNIVERSITY OF TECHNOLOGY
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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING – 621H30001

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Assigned to the student **Lokkeshwar Sai Balachandran**

1. Title of the Project

Investigation of mechanical properties of furniture springs and development of their heat treatment technology

2. Aim of the project

The aim of the project is to investigate the mechanical properties of furniture spring, since the furniture spring when tested did not provide sufficient fatigue resistance and to recommend possible solutions.

3. Tasks of the project

- Analysis of microstructure for identification of microstructural defects
- Determination of mechanical properties of spring wire
- Determination of quality requirements of spring wire
- Determination of cause of failure
- Recommend possible solution

4. Specific Requirements

No specific requirement

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 May 20th.

Task Assignment received Lokkeshwar Sai Balachandran ______________________

Supervisor Dr.Assoc. Prof. Rasa Kandrotaitė Janutienė ______________________

KAUNAS UNIVERSITY OF TECHNOLOGY

Mechanical Engineering and Design

(Faculty)

Lokkeshwar Sai Balachandran

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Mechanical Engineering- 621H30001

(Title and code of study programme)

"Title" of final project

DECLARATION OF ACADEMIC HONESTY

____ __________________ 2017

Kaunas

I confirm that a final project by me, **Lokkeshwar Sai Balachandran**, on the subject " **Investigation of mechanical properties of furniture springs and development of their heat treatment technology**" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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SUMMARY

The main focus of the paper is to analyse the reason for the failure of the furniture springs, since the springs when tested did not provide sufficient fatigue resistance and to recommend possible solutions. It is also to be noted that only cost effective materials and coatings were used, since not many furniture making industries need components of high cost value. The tasks that were done to obtain the reason for the failure of the springs were as follows, the determination of the mechanical properties of the spring wire, analysis of the microstructure for identification of the microstructural defects, and the determination of quality requirements of spring wire. The material used for the experiment was EN 10270 according to the European standard and type of spring under investigation was the sagless or zig zag type furniture spring. For the tempering test, the spring wires were tempered both in company and in KTU laboratory and the results were compared from the specimen coloration. In tensile testing, the specimens were tested using the universal testing machine present in the KTU laboratory, the data from the test was logged using catman express software and from the data obtained the mechanical properties of the spring steel were investigated. Finally, the microscopic analysis of the spring steel was done, in which the specimen was investigated for surface and microstructural defects. The results obtained from the tests were then compared with their respective standards to know if they were within the permissible limit. Thus from the comparative results obtained from the tests, the recommendations for development of production and heat treatment of furniture steel springs were found out.

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Balachandran, Lokkeshwar Sai. Baldų spyruoklių mechaninių charakteristikų tyrimas ir jų terminio apdorojimo technologijos tobulinimas / vadovas doc. dr. Rasa Kandrotaitė Janutienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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Raktiniai žodžiai: baldų spyruoklės, zigzago tipas, lūžis, tempimo bandymas, metalografija, atleidimas.

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SANTRAUKA

Pagrindinis darbo tikslas yra nustatyti zigzago tipo baldų spyruoklių lūžių priežastis ir pateikti galimas rekomendacijas jų terminio apdorojimo technologijai tobulinti. Buvo nustatomos plieno vielos, naudojamos spyruoklėms gaminti, mechaninės charakteristikos, medžiagos mikrostruktūrinė analizė, identifikuojant sandaros ir paviršiaus defektus pagal keliamus kokybinius reikalavimus. Norint nustatyti Įmonėje X spyruoklių terminio apdorojimo galimas klaidas, buvo lyginami eksperimentų rezultatai bandinių, termiškai apdorotų tiek Įmonėje X, tiek KTU laboratorijoje. Pagal gautus rezultatus buvo pateiktos rekomendacijos baldų spyruoklių terminio apdorojimo technologijos tobulinimui.

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ABSTRACT

The purpose of the paper is find out the reason for the failure of the zig zag furniture spring and to recommend a solution to the problem. The mechanical properties like tensile strength, offset yield strength was studied, the microstructure was also analyzed for the cause of the failure. In this paper, the type of spring material used, the type of production and heat treatment of the furniture spring, the making of the zig zag spring, the types of coating used, the different causes for the spring failure etc. are given. The various tests are performed and their results are tabulated and compared using the European specifications for the permissible limit of the different properties like the permissible limit of surface flaws, the limit for decarburization etc. From the obtained results, the recommendations are given to avoid further causes for failure in the production of the springs. This paper is important as it can help in the possible improvement of the fatigue life of the furniture springs.

1. Literature review

This literature review is written to shed some light on topics of varieties of materials used in the production of furniture springs, the production and heat treatment of the furniture springs, the different coatings used on the furniture springs, causes of spring fracture and the different testing methods used on the furniture springs.

1.1. Materials used for furniture springs

An inert link is seen between the materials and their functions. Every material will have their own number of different attributes, namely, a few of the attributes are density, cost, resistance to corrosion, strength, creep, hardness, elastic limit, hardness and so on others, these different attributes should be taken into account when the process of selection of materials take place. The usage of a material is directly linked to the designing of a component. The Fig.1 shows the relationship between the material selection and its shape, function, process [1].

As said before, the material selection is directly linked or interconnected with the function, process, and shape. Functions are basically the ability or characteristic of a material to withstand load or temperature or pressure, to store energy, ability to withstand the adverse environmental conditions etc. The different processes that influence the material such as machinability, weldability, formability etc. are also considered. The shape normally denotes the form or structure of the material like honey comb structure, and also the shape of the device which can be the micro and macro shapes. The capacity to interact with the function, process, shape, and material forms the main basis of material selection [2].

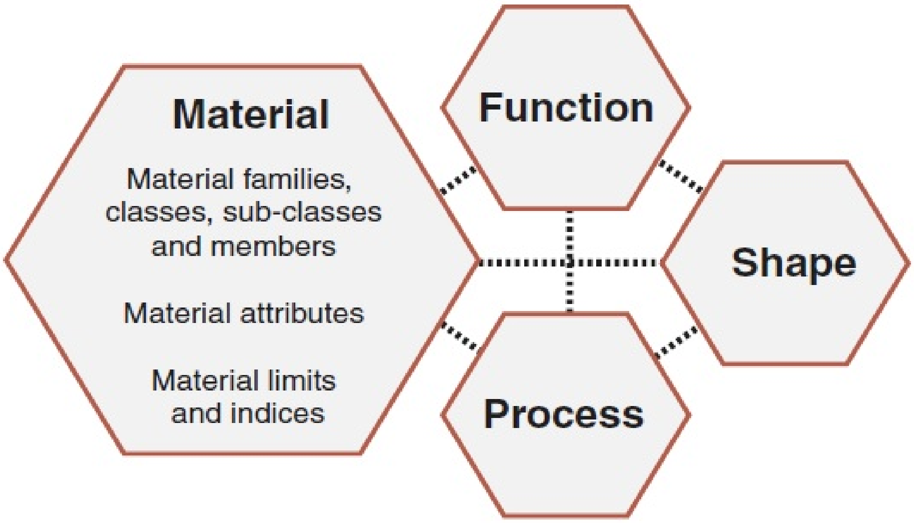


Fig.1. Material selection parameters [1]

Springs are basically components which are designed and produced for their function of undergoing large deflections which are within their elastic range. Hence, it is considered natural to select the materials to be utilized for the spring with a very large elastic range [3]. The materials which are selected and used for this are called as spring material. Even though these spring materials are not specifically designed alloys in spring making since they have an elastic range that is needed to make springs they are therefore desired. In steels, normally the medium and high carbon content are the most appropriate for spring making.

The BIS has recommended four basic varieties of steels for various spring material applications.

1) Patented and Cold Drawn
2) Oil Hardened and Cold Drawn
3) Oil Hardened alloy steel
4) Stainless Steel

Patented and Cold drawn steel are regarded as the most commonly used furniture spring material. It has high strength and can withstand most fatigue loads. They are graded with regards to their operating conditions and their chemical composition. The minimum tensile strengths of these materials are covered by IS: 4454 (Part I)-1981 or in our case EN 10270-1 [4].

1.2. Different Furniture Spring Standards

There are only a few specific kinds of materials which are employed in furniture spring making and their international standards are given below.

1. European Standard

EN 10270

2. American Society for Testing and Materials

ASTM A417

This specification normally covers round, uncoated, cold-drawn spring wire in coils having the properties and qualities which are required for the manufacture of furniture springs or upholstery springs.

This specification covers a variety of springs namely

Type A- which are basically Zig-zag (U-formed),

Type B- Square-formed, and

Type C- Sinuous for furniture spring units.

These types of furniture springs are mostly intended for the use in the manufacture of automotive seats and furniture springs. This wire is not developed for the manufacturing and producing of mechanical springs.

ASTM A407

This American specification is also used in the manufacture of furniture springs and other similar products. They are classified into different types according to their specification and uses.

Type A- Coiled (Marshall pack),

Type B- Coiled and knotted,

Type C- Coiled and knotted (offset style),

Type D-Coiled and hooked (single and cross helical),

Type E- Coiled and hooked (short tension—regular tensile strength),

Type F- Coiled and hooked (short tension—high tensile strength), Type G-regular lacing,

Type H-Automatic lacing,

Type I- Zig-zag (U-formed),

Type J- Square-formed, and

Type K- Sinuous for furniture spring units.

These types of furniture springs also have their use in the manufacturing of automotive seat springs, furniture springs, furniture cushions, mattresses and bed spring units. This wire is not designed or intended for their use in the manufacturing of mechanical springs.

3. Indian Standard

   IS7864-1 -which is a Conical Type

   IS7864-2 -a Zig-Zag Type

4. Japanese International Standard

   JIS G 3521

5. Chinese

   YB/T 5220-93

6. International Organization for Standardization

   ISO 8458-2:2002

7. Hard drawn steel wire

Hard drawn steel has application in various industries, namely, they are made as springs for various products like chairs, beds, toys, cycle saddle springs etc. It also has applications in washer springs, springs for bicycle transmissions, springs used in seat belts as they are made of shaped wire which is manufactured from hard drawn steel.

2. Production of Furniture spring

Before we know about the production process of furniture springs it is mandatory to know about the history of the various processes that are involved.

2.1.History of Cold working of steel

The possibility to work a common metal at ordinary temperatures must have been discovered almost simultaneously along with the discovery of metals themselves, there are abundant of evidence in records that the ancients made proficient operation of cold working processes, not only to shape the metals to their end design but also for the hardening of those metals, Hammering or the act of striking a metal is certainly the most obvious and basic method of shaping a metal, and in the early times of cold working this would have probably been the only cold working process in use, and the processes like rolling and drawing must have started later in time. The Evidence of this is seen in the scriptures, where the reference of the said is made in Exodus, Chapter XXXIX, to the manufacturing of gold wire used in the decoration of the garments of Aaron. Aaron was the brother of Moses and also the first high priest of Israel.

"And they did beat the gold into thin plates, and cut it into wires, to work it in the blue, and in purple, and in the scarlet, and in the fine linen, with cutting work." [5]

Modern methods of cold working metals are as follows wire drawing, cold rolling, tube drawing etc. It was first demonstrated in 1864 by Tresca [6], that pressure can be used to actually make the steel flow through openings.

2.2.History of Wire Drawing

In ancient Egypt and India wires of gold and silver were already being made and used for the making jewelry. Claudius Claudianus, a Roman penman who lived in 400 A.D. reported in his records the finding of wires of gold, silver, and bronze being made.

One of the earliest written accounts of wire drawing was found written by the monk Theophilus during 1122 A.D. in a Westphalian monastery., in which he has described the draw plates [7]:

"Two iron plates three fingers wide, narrow at the top and bottom, thin throughout and pierced with three or four rows of holes of diminishing size through which wires may be drawn"

The first recorded known individual wire drawer was Rudolf a Nuremberg, a German armorer, he was said to have invented the very first wire drawing machine in 1306 A.D., this was quoted from the Darmstandters handbook on natural science and technology [8].

3. Steel Spring Wire Production

The whole series of operations which are involved in the manufacturing of steel wire are tabulated as follows in fig. 2. The cold drawing of wire is divided into two classes.

Class I: In class I, we are dealing with all the wires in which the cold working operation is in most part merely a means of producing a thread of rod of metal of a certain dimension. In this class are the products such as iron and mild steel wires, steel wires for hardening and tempering and most of the alloys steel wires are produced.

Class II: In class II, roping wire, spring wire, piano wire, aircraft wire etc. where the hardening effect of cold work are utilized are produced [9].

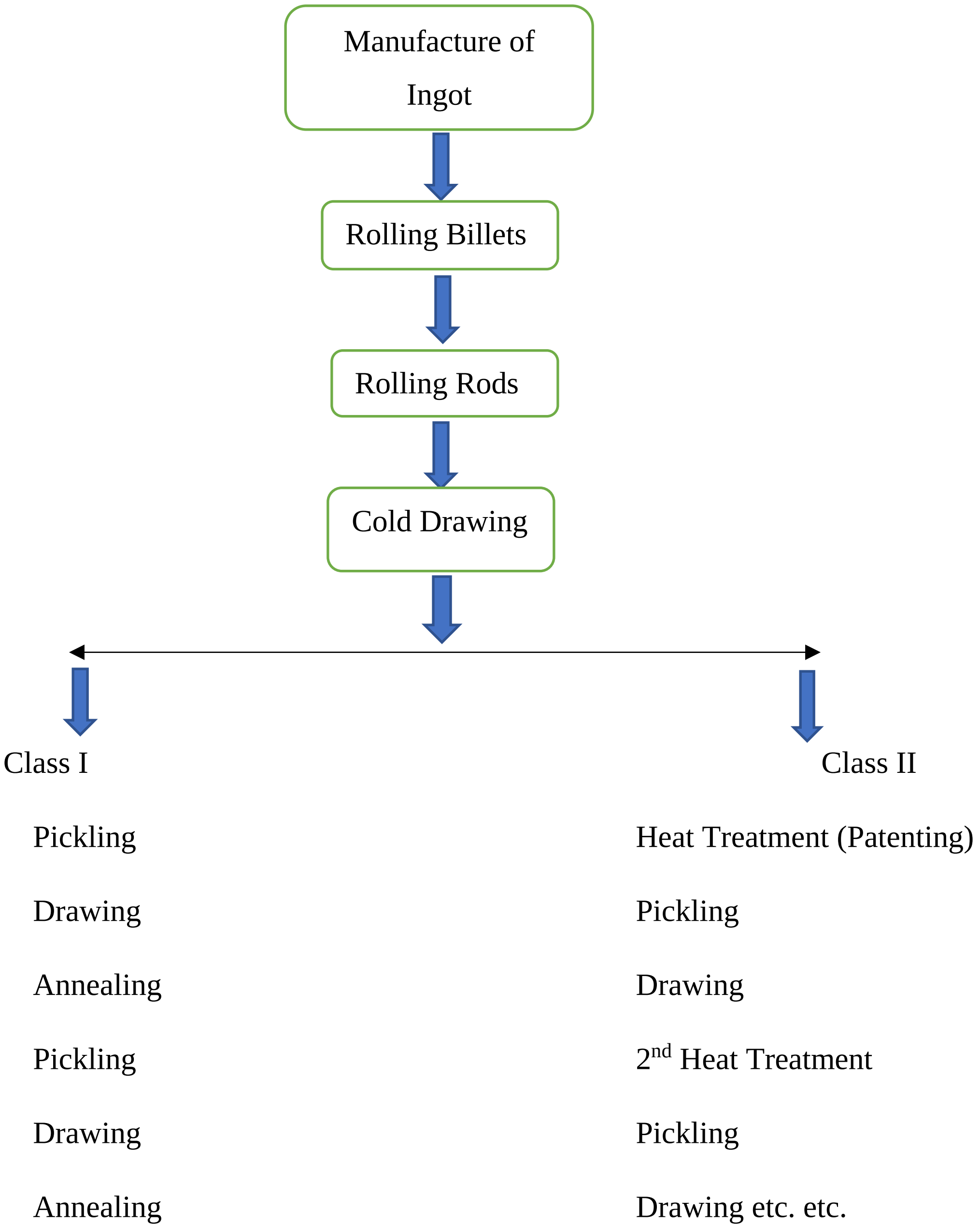


Fig. 2. Operations involving the manufacturing of steel wire [9]

3.1.Cold Working

In tradition, the metal working processes are normally divided into cold working and hot working with regards to the quantity of heat applied to the metal before the application of mechanical forces to it [10].

When the plastic deformation of the metals is performed at temperatures which are below the recrystallization temperature, the process is called as the cold working of metals [11].

The various cold working processes are classified into, Drawing, Bending, Hobbing, Tube drawing etc.

3.1.1. Cold Working Advantages and Disadvantages

Advantages

- Due to the strain hardening, the strength and hardness of the material increases, which is highly favorable in some situations. Furthermore, it is impossible for decarburization to occur.
- No oxide formation is seen in cold working, because of which an excellent surface finish is obtained.
- Higher accuracy in dimension is obtained.
- Handling of the cold formed parts is much easier and is also greatly economical the smaller the size.
- Contamination is at a minimum, because of low working temperatures.
- Some physical properties which do not respond to heat treatments will normally respond to cold working.
- Normally in mass production and in automation cold forming is highly suitable since it is executed at low working temperatures.
- Energy is saved since heating is not required.
- Properties like strength, fatigue, and wear are vastly improved.

Disadvantages

- Because of the high yield strength of materials at lower temperatures, the deformation that is obtained is directly in relation to the capabilities of the presses or hammers that are being used.
- Cold working cannot be done on some brittle material.
- The amount of deformation that can be exerted on the material is constrained as the materials undergo strain hardening. Further deformation can be obtained through annealing.
- A surge in cost due to stress relieving since severe stresses are set up can be seen.
- Complex shapes cannot be produced easily and are limited, due to the limited ductility at room temperatures

3.2.Cold Forming

The process of spring manufacturing process can be categorized into hot forming and cold forming. The hot forming is applicable for bigger sized springs. While cold working can be more efficient when processing small size springs.

Cold working a process where the material is forged at near ambient temperature and, also the cost of cold working is less when it's compared to hot forging.

Cold forging is a process which is normally used in the production of a large number of components with a good net shape geometries and enhanced mechanical properties when comparing them to the machined components. The surface quality of the cold forged components are dependents upon factors like initial surface roughness, the variety of lubrication system employed [13].

As per the statistics from Japanese spring manufacturing association, the proportion of the production weight of hot formed springs to that of cold worked springs is 6 to 4. Nonetheless, in regards to production quantity, cold worked spring are significantly greater, and in regards to the sales, the cold forged surpass the seventy percent of the net amount [12].

Cold forged springs are further classified into wire springs consisting of coil springs, sheet springs for vehicles, flat springs, power springs and spring hanger clips.

Amidst the different cold formed springs, the most recurrent type of springs is wire springs and flat springs. In regards to spring material, the material used by wire springs are mostly ferro materials, while nearly all flat springs use nonferrous materials.

By using pre-hardened materials, the cold forged spring show very good dimensional accuracy. When the material is pre-hardened they are not used in precipitation hardened springs and some other types of springs. The cold worked spring material show excellent formability to meet with the mass production.

3.3.Cold Drawing

Cold drawing has major use in our modern industries. We know it as the uttermost ancient metal forming process in use till today. It is mostly used because of its advantages like closer dimensional tolerances, better mechanical properties, and an enhanced surface finish when compared to the hot forming process.

3.3.1. Cold drawing process overview

The cold forming process involves the reduction of rod, tubes, bars, wire or any other cross sectional area metal by drawing it through a die. It also provides total control over the dimensions and an excellent surface finish which is obtained in long products which have a constant cross section. The process can be classified into

:

- Tube Drawing: Large diameter tubes are sized into smaller ones by drawing the tube through a metal die in this metalworking process Fig. 1b. It is suitable for any scale of production, make it suitable for both small and large scale production.
- Wire and Bar Forging: In wire or bar drawing the metal bar or a wire is passed through a die opening Fig. 1a. This can be compared to extrusion but has an exception where the workpiece is drawn through a die while in the former the workpiece is pushed to create metal objects which have a fixed cross-sectional profile. The metal gets deformed as it moves through the die opening due to both compressive and tensile stress.

Since the products obtained from this process has a superior surface finish and a higher control over the dimensions, it has seen a good commercial value., due to this market value, the forming process has seen a lot of process improvements and has been extensively researched till now [14].

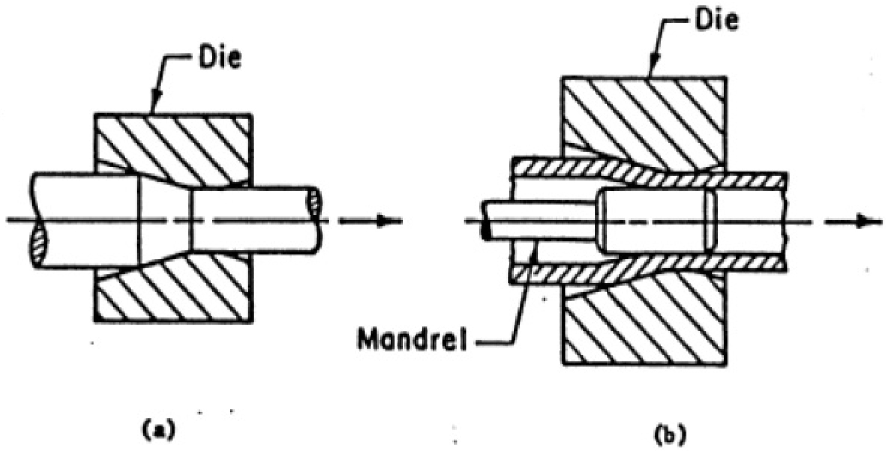


Fig. 3 Types of Cold drawing (a) wire and bar drawing and (b) Tube drawing [14]

3.4.Wire Drawing

Wire forming as define by Heinz Tschaetsch [15], is a form of cold working using sliding action, where wire of a greater diameter (d_0) is drawn through a forming ring of smaller size (d_1).

In wire forming a difference could be made with respect to the dimension of the wire, which are

The coarse drawing which has a diameter of 16 to 4.2 mm, medium drawing with a diameter of 4.2 to 1.6 mm, the fine drawing with a diameter of 1.6 to 0.7 mm and ultra-fine forming which has a diameter that is even lesser than 0.7 mm.

Wire forming process is an operation which involves the reduction of the diameter of a steel rod by pulling the metal through a die hole by the use of tensile forces at the end side of the die. The iron or steel rods are basically converted into wires by passing the rod through a conical hole which has an angle of 9-23 degrees. It is to be taken into consideration that the rod end gets tapered sufficiently to be passed through the first die by using pointing machine and the successive drawings should be done at higher speeds.

The wire gets passed through a succession of holes in the process of continuous wire drawing, where the holes are basically of decreasing sizes.

The material of the dies which are used in the wire forming process can be made of steel, ruby, diamond or tungsten carbide. Ruby and diamond dies are basically used in drawing fine wire which is of less than 3mm diameter.

In recent time the steel dies are gradually being replaced by tungsten carbide dies as they provide the maximum efficiency. The cross-sectional area reduction of the rod normally begins at about 30 percentage.

A few of the preparations that are necessary to be done before the drawing processes are the cleaning of the wires and the lubrication of it as it gets passed through the die. Cleaning is done to descale and remove any of the rust that may be found on the wire's surface if it's not cleaned properly it may cause damage to the die. This cleaning can be accomplished by using acid pickling. Since there is a lot of pressure acting between the rod and the die, it normally has to be lubricated properly, this lubrication can be obtained by special methods such as sulling, phosphating, and liming. Sometime lubrication can be done by passing the rod through dry soap on its route to the die, some synthetically designed lubricants are forced through the die and sometimes even some separate cooling equipment are used for lubrication.

At present, a very fine wire is being obtained and produced. This is done by using composite wire drawing. A Platinum wire which is only 1/30,000 inch in diameter has been produced which is for instance only many 1000 times thinner than a human hair, this was accomplished by drawing the wire by encasing the platinum wire in silver, thus increasing the overall diameter to a practical size. Once the drawing has been accomplished the silver got dissolved into the nitric acid leaving only a platinum wire which was only visible to the naked eye under a microscope.

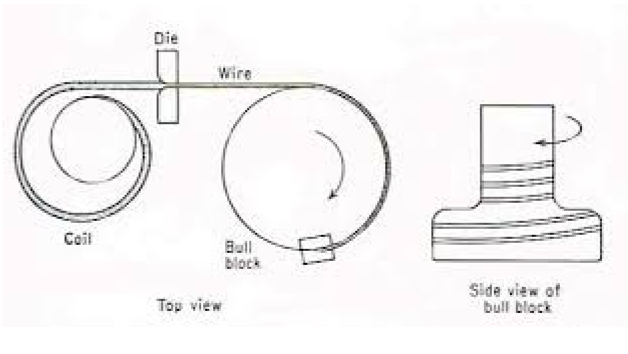


Fig.4. Wire Drawing [11]

The Wire forming operations normally involve the presence of intermittent annealing so that the work hardening and flow stress during the wire drawing operation is minimized [15].

3.5.Cold Formed Furniture Springs

The tensile strength of the wire can be increased, by quenching the wire immediately from its rolling temperature (tempered hardening) and finally gets drawn to the required size in 2 to 4 passes. The ultimate strength which is attained by this treatment normally averages to about 100 kg/mm^2. Water hardened spring wire are used almost exclusively for upholstery springs (Furniture Springs) [16].

4. Heat treatment

The main objectives of the heat treatment are as follows [17]

- It is used to relieve the internal stresses that have been developed because of the different workings of the steel namely cold working, welding, casting as such;
- Heat treatment used on alloys help in homogenizing the grain composition;
- Heat treatment of steels also improves their different mechanical properties like ductility, yield strength, hardness, tensile strength etc.;
- Heat Treatment has its uses in developing specific properties like improving the surface hardness coupled with the tough core, and to make it corrosion resistant, etc.;
- Heat treatments can also be used in modify the structural properties of the material so that we can acquire the required magnetic and electrical properties.

4.1.Heat treatment of springs

Springs get made from high carbon steel containing different alloys like chromium, silicon, magnesium, and molybdenum, the most commonly used is silicon steel since it is comparatively cheaper and it does not contain any expensive alloying elements. Silicon steel is much simpler to heat and has a good elastic limit.

While heat treating springs, it should be noted to observe them as to prevent them from changing their dimensions and shape. This can be accomplished by heating and quenching the steels in a vertical direction. To prevent the springs from getting distorted, the furnace bottom on which they are placed for heating must be even and smooth. Small thickness gauged wires are normally fitted on mandrels before the heating process to prevent wrapping.

As all steels are liable to decarburize, they should normally be held at a higher temperature for the minimum possible time to avoid decarburization.

Faults in springs occur due to decarburization during heat treatment, segregation, internal cup and cone fractures due to overdrawing, lapses due to rolling, scratches due to wire drawing, scoring due to winding and incorrect tempering [18]. The heat treatment that gets widely used is patenting.

4.1.1. Patenting

In the seventies of the 1800 A.D., a new process of steel wire production was used in England, this process was a special heat treatment called patenting, which was done before the wire got drawn. This process is currently the most used process in spring making [19].

Normally furniture springs are patented cold drawn. Steel wires with a carbon content that is greater than 0.25 percent undergo patenting heat treatment. This consisted of heating the wire above its upper critical temperature and then cooling it at a controlled rate or transforming it in a lead bath at temperatures around 315°C causing it to form fine pearlite. Patenting is used in producing the best combination of strength and ductility that is required for the successful drawing of the high carbon music and spring wire [20].

The heat treatment process in which high carbon steel is continuously transformed to patented sorbate microstructure by isothermal cooling or continuous cooling is called as patenting.

It is a common process in which the rod for the wire making that is traveling continuously is heated to 950°C to form an austenitic structure and then gets rapidly quenched at 500°C in a molten lead bath to form the patenting sorbite formation which has high strength and ductility.

After remaining there for a while, the wire leaves the bath and enters the normal temperature, by patenting the steel rod will get a sorbate structure suitable for drawing [21].

The quenching medium for patenting of wires is of several types namely air, lead, boiling water and sand that is floated and fluidized by a mixture of air and combustion gasses. These quenching mediums used in patenting are called as air patenting, lead patenting, Easy draw type etc.

There are several direct patenting methods which can control the cooling speed of the rod, these have been developed to replace lead patenting the first kind of patenting in wire making. The direct type of patenting is of three different kinds namely: Stelmor type which is air type, it is considered that the stelmor type of patenting is one of the more successful types of patenting method which has largely replaced lead patenting method. EDC or Easy draw type is where the hot rod is continuously soaked in boiling water and the Direct inline patenting or DLP is the one in which the rod is continuously soaked in molten salt held around 550°C.

The properties of the spring wires are directly influenced by the patenting process.

It plays an important role as it ensures uniform and fine microstructure of sorbite, isothermal transformation temperature and period, rigorous quality control is demanded on the heating temperature and period, and so on.

The patenting furnace is designed in such a way that the inner atmosphere is controlled to stop the occurrence of decarburization of wire. The tensile strength of the patented wire is dependent on several factors namely its size, composition, namely the composition of C carbon and Mn manganese contents, and the transformation temperature. The tensile strength obtained is also directly dependent on the drawing reduction and the composition of the rod. It is very important to properly control the transformation temperature, the chemical composition of the rod and the size of the wire so that the tensile strength can be adjusted within the prescribed ranges [12].

4.1.2. Pickling

The removing of the surface scales or ferrous oxide in patented wire or hot formed wire is called as pickling, this is done using hydrochloric acid or H_2SO_4 solution. Pickling lasts for 6 hours to 24 hours depending on the grade of steel, the state, and temperature of the pickling bath and the nature of the scale formed on it [22].

The bath for pickling is made by mixing the required amount of sodium chloride and saltpeter in separate tanks. The solutions in the different tanks are then poured into a working bath and water is added, after which sulfuric acid is added in small amounts with agitation. A turbid solution of NaF is added last, with agitation.

The pickled part is then rinsed by dipping it in cold water wash, traces of scales are removed by subsequent water washes, it is to be noted that the pickling process is completed before washing the part in cold water. Pickling is considered complete if the surface of the part shows an even bright gray coloration when it’s rubbed.

4.1.3. Annealing

In general, annealing is used to make the metal soft by heating it to a high temperature and then cooling it at a slow rate, a few of the purposes of annealing are as follows,

- It is mainly used for softening the steel to improve its machinability;
- For relieving the internal stresses that have been caused due to previous treatments like forging, welding, rolling etc.,
- Used in refining the grain size;

- Also, used in removing different gasses that have been trapped up during the process of casting of metals.

The basic process of annealing is namely, heating the steel to the desired temperature per the type of annealing done and by keeping it at that temperature for a period to allow the required structural changes to occur, at last, cooling it at a slow rate [17].

4.1.4. Annealing of Cold- Worked Metal

The metals will normally have an increased internal energy in a cold worked state than the unformed metal. Though the dislocation cell structure is mechanically stable in a cold work state, it is unstable thermodynamically. When the temperature of the cold formed metal is increased, it becomes unstable. With the increase in temperature, the cold formed metal will soften and it will revert to its strain free condition. This process is called as annealing. The reason why annealing is very important in industries is because it is used in the restoring the ductility of a metal, which had been strain hardened. With the use of intermittent annealing, we can obtain the required deformation for most of the metals [20].

5. Zig-Zag Spring Making

Once the wire making process is completed the next stage is the production of zig zag springs from the spring wires. Zig zag springs are also called as sinuous springs, sagless or no sag springs and are found in most of the modern furniture’s, they can be procured in gauges from 8-13. The wire is fed through a wire straightening machine. The straightened wire obtained is then fed to the Zig Zag forming machine as shown in Fig.5. The produced spring is later fed to a knotting machine to complete the process, the spring is finally inspected and packed.

Fig.5. CNC Zig Zag spring forming machine

Materials	Heat Treatment °C
1. Patented and cold drawn steel wire	190-230
2. Tempered steel wire:	
Carbon	260-400
Alloy	315-425
3. Austenitic stainless steel wire	230-510
1. Precipitation Hardening stainless wire:	
Condition C	480/1 hr
Condition A to TH 1050	760/1 hr
	Cool to 15°C followed by 565/1hr
1. Monel:	
Alloy 400	300-315
Alloy K500, Spring Temper	525/4hrs
2. Inconel:	
Alloy 600	400-510
Alloy X-750:	
#1 Temper	730/16hrs
Spring Temper	650/4 hrs
Annealed Steels:	
Carbon (AISI 1050 to 1095)	800-830
Alloy (AISI 5160H 6150, 9254)	830-885

Table 1. Typical Heat Treatments for springs after Forming [21]

The heat treatment that was done for the specimens that are being used in this project were patented and cold drawn.

6. Effect of Alloying Elements

Steels normally contain various alloys and impurities, the effects of these different alloys and heat treatments, develop many different microstructure and properties. It is to be noted, that the effect of one alloying element is modified by the influence of other elements. Therefore, the interactions of the different alloy elements must be considered [23].

Alloying elements are split into two types with respect to their interactions with carbon in steel:

1. Mn, Cr, W, Nb, Mo, V, Zr and Ti which are carbide-forming elements which go into the solid solution of cementite when they are in low concentration and they also form stable alloys of carbides at higher concentrations.

2. While the elements such as Co, Si, Ni, Cu, Al and P do not form any carbides in steels they are present in a matrix.

The effects of few of the alloying elements are listed below

Carbon - Normally the carbon content of steel determines the type of steel that can be produced. Carbon is the vital element used in the hardening of the steels, excluding precipitate hardening stainless steels, interstitial- free (IF) steels and managing steels.

With the increase in the carbon content of the steels, the strength of the steel increases but has a diverse effect on the ductility and weldability, as it decreases with higher the carbon content [23].

Manganese – It is a primary component in steels, it is found in all forms of steels in percentages of 0.30% and more [25]. Manganese deoxidizes and desulfurizes [24]. Manganese is beneficial to Surface quality and it also positively affects the weldability and forgeability.

Silicon –The silicon content also determines the form of steel that is produced. It is used to reduce the oxygen content used in steel making. When silicon is combined with Manganese or Molybdenum, Si produces an increased hardenability in steels [23]. It is also used for increasing the wear resistance, elastic limit and yield point in heat treated steels.

Phosphorus – Phosphorus affects steel in such ways that when the quantity of phosphorus increases the ductility and impact toughness of steels decreases [23]. P is also used in increasing the hardenability and decreases the decomposition in martensite, like Si in steels.

Sulfur- Sulfur in the quantity of 0.08-0.33% is always added to free machining steels to increase the machinability, also the increased amounts of sulfur (S) normally causes hot shortness. Sulfur is also used to improve the fatigue life in bearing steel [26].

Aluminum- Aluminum has its uses as a grain refiner and as a deoxidizer [27]. When considering all the alloys, it is seen that Aluminum is the most effective alloy when it comes to controlling the grain growth before quenching.

Nitrogen – Nitrogen is used because it expands and stabilizes the austenitic structure, and is also considered as a substitute to Nickle in austenitic steel.

Chromium- Chromium is normally used as a carbide former. It is considered as an essential alloy in steels, by adding chromium in steels, they enhance the impurities like P, Sn, Sb and As by segregating it to the grain boundaries and also by inducing temper embrittlement.

Nickle – It forms non-carbide elements in steels. Nickle (Ni) improves the hardenability. When Nickle is made to combine with chromium and Molybdenum it hugely improves the hardenability, impact toughness, and fatigue resistance in steels [28].

Molybdenum – Is one of the pronounced former of carbides. The addition of Mo can produce fine grain steels, increased hardenability and improves the fatigue strength. High Mo content reduces the effect of pitting in stainless steels [29].

Copper - Copper increases hardenability, also tends to segregate.

7. Coatings of Furniture Springs

The coatings used in furniture springs are as follows, it is to be noted that they should also be cheap since the springs are only going to be used in furniture.

7.1.Phosphate Coating

It is a conversion coating process which uses phosphoric acid in order to cover the surface by adhering phosphate coating through electro-chemical reactions. The reason for using phosphating is that it provides the metal surface with beneficial properties.

7.1.1. Types of Phosphate Coatings

Phosphate coatings are of three types namely zinc phosphate, iron phosphate, and manganese phosphate. The iron phosphate coatings are classified into two types, one which is obtained from baths of high temperature which contain ferrous phosphate and phosphoric acid and the other coating is obtained from baths that contain alkali metal phosphate or ammonium phosphate.

The first to be commercially used is the former which is called as a ferrous phosphate process. Now, it is of less commercial importance.

Thicker coatings which are more than 5 g/m^2 are produced from the process. These types of coatings are known as heavy coatings and, when used together with an oil or a wax, are used for corrosion protection.

A substance like oil and wax is spread on a fresh coating, this is done after the component is rinsed and dipped in a solution of dilute chromate. They are dark, crystalline, and consist mainly of $Fe_5H_2(PO_4)_4.4H_2O$ or hureaulite.

The different $FePO_4$ or ferric phosphate coatings that are acquired from the baths of alkali metal or ammonium phosphate are of the follows alkali-metal phosphates, low weight iron, and ferric phosphate.

These are normally a very thin type of coating, presented in thicknesses which are less than 1.5 g/m^2, the name low weight iron is obtained because of this flimsy character. In accordance to D.W.Bloor [30], the nature of the iron phosphate coating is crystalline, but they are considered amorphous since they consist of very fine crystals. An iridescent blue to a reddish blue interference color range are normally seen in the above-mentioned coatings.

A mix of iron phosphate, vivianite ($Fe_3(PO_4)_2.8H_2O$) with 70–80% of iron oxide, the magnetite (Fe_3O_4) are used to form the coating [30], This form of phosphate coating isn't pure. These could be formed by either dipping or spraying. These are cheaper than any other forms of phosphate coating technique.

Their use is of base coat for paints or a base coating for the further subsequent paintings, it provides best characteristics when used in non-aggressive environments, they aren't developed for the use in a vigorous environment like in humid, watery conditions because the iron oxide of the phosphate layer may get altered into non-protective oxides which may be detrimental. These coatings also act as a suitable surface for bonding between fabric and metal, wood, and other materials.

Similarly, the formation of zinc phosphate coatings is done using baths containing mixtures of zinc phosphate, phosphoric acid, and some accelerators namely nitrates, chlorates etc., the application is done by either by dipping or by spraying techniques.

When comparing the costs, the zinc phosphate techniques are not cost effective and are costlier than the iron-phosphate techniques and they are mostly used in the car manufacturing industries, as they satisfy the requirements for their use in the automobile sector. These zinc phosphate coatings are mostly crystalline in nature and their color varies from light to dark gray. They consist of hopeite or $Zn_3(PO_4)_2.4H_2O$ and phosphophyllite or ($Zn_2Fe(PO_4)_2.4H_2O$).

The operational condition and the compositions of the bath determine the relative quantity of each phosphate [30]. The layer rich in iron is the closest to the substrate and as the distance from the surface is increased becomes poorer in iron.

Zinc-phosphate coatings have a variety of uses, they are used, as a base for paints for corrosion protection; a base for oils and waxes for corrosion protection; an aid to cold working processes; a support to tube or wire forming; an aid to sliding operations; and to increase the wear resistance. Iron phosphate coating is used as a base when higher corrosion protection is required, its use is mostly in more aggressive environments, as a base for paints, they present better performance than iron phosphate coatings.

From calcium salt containing phosphate baths, zinc-phosphate coatings can be obtained. In such cases, with regards to phosphophyllite and hopeite, scholzite ($Zn_2Ca(PO_4)_2.2H_2O$) is present in the coatings. The crystals get refined with the use of calcium salts as the additive.

In normal conditions, zinc phosphate coatings which are modified by calcium and zinc phosphate coatings could be used to provide sliding.

By the addition of salts of nickel and manganese to the phosphating baths, zinc-phosphate coatings can also be modified. In this case, $Zn_2Me(PO_4)_2.4H_2O$ is added to the zinc-phosphate layer, where the Me can denote nickel or manganese but the main coating constituent continuous to be zinc phosphate.

Grain refinement and enhancement of the property of resistance to corrosion of the phosphate layer can be obtained by the adding nickel and manganese. Trication phosphate is the name of the obtained coating. The density of phosphate zinc coatings ranges from one to forty-three grams per meter sq., and most often from one to twenty grams per meter sq., and flimsier coatings can be up to ten grams per meter sq., are usually gotten from baths excited by nitrite, and are applied by dipping or spraying. The thicker coatings higher than 5 g/m^2 are put to use by dipping and to are useful in cold forming processes and sliding, and also to enhance the corrosion resistance after application of oil [31].

By dipping in high-temperature of about 85–95°C in manganese phosphate baths, the manganese-phosphate coatings are obtained. They are of shimmering black color and have almost exclusively been used, only after the process oiling to increase the resistance to wear, also to promote sliding, and to improve the resistance to corrosion. Occasionally, they are favored mostly because of their shimmering dark color [32, 33].

One of the advantages of manganese phosphate coatings is they are resistant to high temperature, and this resistance causes them to get heated up to two hundred degrees Celsius with the absence of characteristic losses.

They have a crystalline structure and consist of hureaulite $(Mn,Fe)_5H_2(PO_4).4H_2O$). Their thicknesses can vary from 3 to 20 g/m^2.

7.1.2. Phosphate Coatings for Cold Forming Processes

The use of phosphate coatings to facilitate cold working operations were first described in 1934 by Singer [34,35]., The phosphate coatings were used in Germany as an aid for metal forming during the Second World War.

Many manufacturing operations were adopted from the cold forming processes, some of these are tube drawings, wire and bar drawings, and deep drawings.

Without reaching extreme temperatures of more than 500°C and without metal pre-heating forming is involved in all these processes.

Because of this very good lubrication of the surface of the metal is compulsory. This enhanced lubrication would be impossible without the use of conversion coatings.

7.1.3. Applications

Conversion coatings or phosphate coatings are coated on ferrous metals, zinc coated steel, aluminum and steels coated by cadmium. The coatings are used as follows [36-38]:

1. They enhance the bond between metallic and non-metallic materials namely plastic, wood, fabric, rubber etc.;
2. They improve the resistance to corrosion of the above-said metals;
3. They Improved the paint performance that is adherence and corrosion resistance when coated on to the metals mentioned earlier;
4. They help in cold working processes;
5. They allow sliding action
6. Improved resistance to wear and
7. Ensures resistance to electricity

They cannot present the above-mentioned functional properties without additional treatment.

As per the needed properties, the products of coatings like dies, oils, waxes, inorganic or organic sealants, paints etc., are applied on phosphate.

Protective sealants are painted on to the freshly coated phosphate coating after rinsing and dipping them in a diluted solution of chromate (passivation) if a protection to corrosion is required. While in the case of small-term in-plant storage requirement, phosphate coatings will be able to protect the surface only in arid atmospheric conditions.

8. Spring Failure

A few of the common reasons for spring failure is shown in the table below

Fracture	**Fracture with repeated stress** • Fatigue with no corrosion • Corrosion fatigue • Fatigue from fretting corrosion wear **Fracture with impact stress** • Brittle fracture (low-temperature brittle fracture) • Ductile fracture **Fracture with static stress** • Stress corrosion cracking • Delayed fracture (hydrogen embrittlement fracture)
Deformation (Permanent set)	• Yielding, plastic deformation (due to over stressing) • Static creep • Dynamic creep • Stress relaxation
Decrease of cross-sectional dimensions	• Wear • Fretting • General corrosion • Local corrosion • Errosion

Table 2. Common Spring Failure Causes [43]

8.1. Spring Failure

The detailed explanation for the cause of failure of springs are given below

8.1.1. Fatigue Fracture

Mechanical springs, airplane wings, connecting rods are few of the well-known examples of machine and structural components that are subjected to a number of cyclic stresses or loads during their service time. Such type of components fail during their service due to fatigue.

It has been seen that the fatigue failure can occur in components well below their yield strength, when or if a very high amount of stress is applied to it [39].

The fracture caused by fatigue or fatigue fracture occurs because of crack propagation. In this instance, the crack caused by fatigue will initiate at the surface of the part and will slowly propagate firstly towards the interior of the part, at some point the crack propagation increases rapidly, cumulating in a fracture.

Fatigue fracture can be circumvented by improving the fatigue life of the part, a good component design plays a big part in the enhancement of the fatigue life of the part, for example, designing sharp corners in a component should be avoided, by doing this, the regions of accumulation of stress does not occur, Surface finishing also plays a major part in stopping the initiation of crack, by surface polishing we are reducing a few of the irregularities which may initiate a crack growth. The fatigue strength of the part can be enhanced by the introduction of methods like shot peening which applies compressive stresses at the surface thus enhancing it. Using the process of carburizing and nitriding on the part stops crack initiation by forming a strong surface layer on the component.

8.1.2. Mechanism of Fatigue Fracture

A single load cycle cannot cause fatigue fracture; it’s not a phenomenon caused due to a single cycle of load. Fatigue is initiated by the generation of minute cracks, which propagates gradually into final fracture, this is called as crack propagation. Fatigue crack can usually be initiated by cyclic plastic deformation namely slip near the surface. Persistent Lüders bands are formed due to the stretcher-strain marks which are formed in the starting stages of stress cycle and is perceivable microscopically even on polished surface. These persistent stretcher-strain marks start forming rough surfaces with extrusions and intrusions, where the stress can be focused to form micro cracks [40].

Striped pattern called striations can be sometimes observed in fatigue fractured surfaces. Thus, it can be stated that the formation of cracks in fatigue could be because of shear stress and the crack propagation can be because of normal stresses. The cracks generated along the stretcher-strain marks are known as Stage 1 cracks, and cracks propagating in the perpendicular direction to normal stresses are known as Stage 2 cracks [41].

8.1.3. Conditions affecting Fatigue

A few of the conditions affecting fatigue are shown below

Surface preparation: The initiation of fatigue cracks normally starts near to the surface of the component; therefore, the state of the surface is an important factor in fatigue fracture and fatigue life of the component.

It has been seen that the removal of any marks or other surface irregularities greatly increases the fatigue properties of the part. Also by using methods such as shot peening or any other surface treatment, that puts the surface under compression, improves the fatigue life of the component.

Effect of temperature: The properties of fatigue of the part are affected by temperature, this also shows relation to tensile strength. In regards to temperature, it has been noted that the fatigue strength of the part is the highest at low temperatures, while with the increase in temperature the fatigue strength of the part gradually decreases.

Frequency of stress cycle: Normally the number of stress cycles have a very low effect on the fatigue life of most metals, but still lowering the frequency of the stress cycle has a slight effect where it reduces the fatigue life [42].

8.1.4. Microstructure defects in spring steel

The metallography of spring steel has a close relation to their mechanical properties. From observing the metallography, it is possible to confirm if the spring steel has experienced a proper heat treatment. Light microscopes are primarily used to observe the microstructures. Scanning electron microscopes, transmission electron microscopes and others like such are employed to observe finer microstructures. Transmission electron microscopes can perform analysis used to identify fine precipitates.

Recently, with increased cleanliness of steels improving constantly, studies show that a critical inclusion size (CIS) could be seen [43,44], below which breakage caused by fatigue crack in high strength steels in the very high cyclic fatigue region doesn't start from the inner inclusions but could commence from some interior inhomogeneous microstructures [45-53]. The generation of these inner inhomogeneous microstructures predominantly takes place through the operation of heat treatment, while closely relating to the quenching and the tempering temperatures. In few steels having a tempered martensite structure [45-46], the inhomogeneous microstructure being the reason for interior crack generation is mostly the bainite obtained from the imperfect transformation of the austenite at the time of quenching.

For a few duplex phase steels such as the bainite or martensitic steels [47-49], ferrite or pearlite steels [48-49] and ferrite or austenite steels [50], the interior crack generation caused by the inhomogeneous microstructures could be due to the coarse bainite [47-50], the periodically generated ferrite grains [47] and or the ferrite grain matrix [43-50], correlating to the soft phase in the microstructure of the steel.

Moreover, it must be observed that the fine granular area (FGA) [54], occasionally can be seen near to the region of these homogeneous microstructures [45-47,51] but every so often can't be perceived even in the life regime further than 108 cycles [45,46]. Apparently, the initiation of the interior crack and propagation mechanisms developed by the inhomogeneous microstructure are separate due to those developed because of the inclusions.

There are many publications that talk about the relation between the mechanical and the machining properties of steel and additive elements in steel microstructure. Adding elements to molten steel during continuous casting may introduce inclusions to the microstructure of the strand, which affects the microstructure configuration of the casted steel. In addition to inclusions, many other defects can also be introduced into the microstructure of steel.

A few of other microstructural defects are of the following

8.1.5. Non-Metallic inclusions

Non-metallic inclusions mainly comprising of oxides and sulfides and other compounds are formed during the operation of steelmaking, some of which persists in the steel, and others of which those formed by external influences, like damages from refractory products. The fatigue life of springs is affected by these different forms of non-metallic inclusions, so their properties, size, and quantity must be evaluated.

When non-metallic inclusions are near the steel surface, precautions should be taken, depending upon their properties and size they may end up becoming the cause for the point of initiation of steel fracture.

Optical microscopes are used to gauge the non-metallic inclusions, the form of nonmetallic inclusions and also the amount of nonmetallic inclusions are measured to determine the amount of cleanliness of the steels [55]. A light microscope is employed to determine the ratio of nonmetallic inclusions as the percent of total area with regard to the quantity, it is determined with the point counting method.

The effect of non-metallic inclusions and the identification of inclusions is extremely important, with the increasing design stresses, the essential quality of springs in present times, and the enhanced life valve of springs and such, but instead of quantity, the size and form of the nonmetallic inclusions especially, are seen as more of a serious problem.

This is because of the high-stress performance of springs, thus increasing their vulnerability to notching, and also nonmetallic inclusions which are stiffer than the base metal become the starting point of fatigue fracture, ending in failure.

Also, to calculate the size of nonmetallic inclusions near to the surface, a test method which uses the penalty point method has been made consistent by the Japanese spring manufacturing association [56].

In this approach, large penalty points are assigned to nonmetallic inclusions near the surface in particular; the larger the size, the higher the point score.

The determination of the size is done by quantifying the largest non-metallic inclusions in the direction perpendicular to the material processing direction on the polished surface of the test specimen, prepared in conjunction with the material processing direction.

In day to day fatigue design, a normal stress of nearly 10^7 repeated cycles was normally used as the fatigue limit. But in recent times, nonetheless, the serviceability time of the component has been extended, such that for some components an amount of nearly 10^{10} cycles is being applied. Under circumstances of these such high cycles, it has been seen that nonmetallic inclusions contribute to the cause of the failure [57], so the assessment of such nonmetallic inclusions will carry on to be a major issue. Furthermore, research is being taken up into the use of extreme value statistical processing approaches to calculate the size of nonmetallic inclusions and conduct a calculated assessment of fatigue limit [58].

A few of the other methods used for determination of non-metallic inclusions are electron beam melting [59] and acid dissolution [60], and these techniques are applied to calculate the effects of the different types and sizes of non-metallic inclusions on fatigue strength.

Sorts	Characteristics
Type A inclusion	Inclusion like sulfide and silicates with viscous deformation in processing. When necessary, subdivide into A1 inclusions sulfide and A2 inclusions silicate.
Type B inclusion	Granular inclusions like alumina etc., forming groups discontinuously in the direction of processing. In steel containing Nb, Ti and Zr, when necessary subdivided into B1 inclusions, almina and other oxide and B2 inclusions like Nb, Ti or Zr carbonitride.
Type C inclusion	Type C includes Irregularly distributed inclusions like granular oxides. With no viscous deformation. In steel containing Ni, Ti or Zr which can be independent or in combinations of two or more, when necessary subdivided into C1 inclusions oxide and C2 inclusions Nb, Ti or Zr carbonitride.

Table 3. Types of non-metallic inclusion [55]

8.1.6. Decarburization

When steel materials like spring steels are exposed to a really high temperature, decarburization takes place, the reaction of carbon in the steel with O, CO_2, moisture, H and other atmospheric gases, the chemical reaction causes them to escapes into the air, this is shown in Equations (1.1), (1.2) and (1.3), thus depleting the carbon content in the steel's surface.

$$2C + O_2 \rightarrow 2CO \ldots.. (1.1)$$

$$C+CO_2 \rightarrow 2CO \ldots.. (1.2)$$

$$C+H_2O \rightarrow CO+H_2 \ldots (1.3)$$

The carbon which is found in or around the steel surface reacts with the reactive component in the air, thus resulting in the reduction of the carbon concentration. The decarburization process is further accelerated by the presence of carbon on the inside of the steel which gets scattered to the surface, promoting the process of decarburization. The reaction of decarburization is only worth paying attention to in the gamma phase steel, but not in the alpha phase steel. Decarburization seen in spring steel has detrimental effects namely, it decreases the steel hardness at the surface of the spring, which in turn decreases its fatigue strength.

Precaution should be exercised in regards to decarburization when spring steel is heated and when the spring is heated during the spring forming process.

As per JIS [61], decarburized layer's depth is quantified by perceiving the steel with a light microscope and by taking the concentration of hardness and carbon. Most cases, the assessment is done by visual inspection using a light microscope. Different techniques for showing the decarburized layer consists of total decarburized layer depth and ferrite decarburized layer depth. The total decarburized layer depth indicates the depth from the upper surface of the decarburized layer to the base metal, to the point at which it is impossible to differentiate the variables in chemical or physical properties. Ferrite decarburized layer depth indicates the depth from the surface of the level where the steel surface is decarburized and becomes ferrite. There are several standards including JSMA standard which are used as the procedure for quantifying the decarburized depth of steel wire for spring producers [62]. The other method known is the chord method [63], used in measuring the hardness at the decarburized layer depth. Other procedures incorporate the usage of electron probe x-ray micro-analysis to calculate the depth of the decarburized layer and perform a carbon analysis.

8.1.7. Surface Flaws

The flaws which are found on the spring's surface play a major role on the fatigue life of the surface. By the introduction and use of high-stress performance springs in present times, even minute defects may become the initiation point of fracture. Moreover, the production line is almost fully automated, so if a surface defect does exist, that defect might develop into the starting point for fracture during the manufacturing, which might cause problems in the production line.

Inspection of surface defects is of importance. Nondestructive testing methods are standardized by JIS [64-67]. Fig.6 depicts a comparison of the various nondestructive type of tests [68].

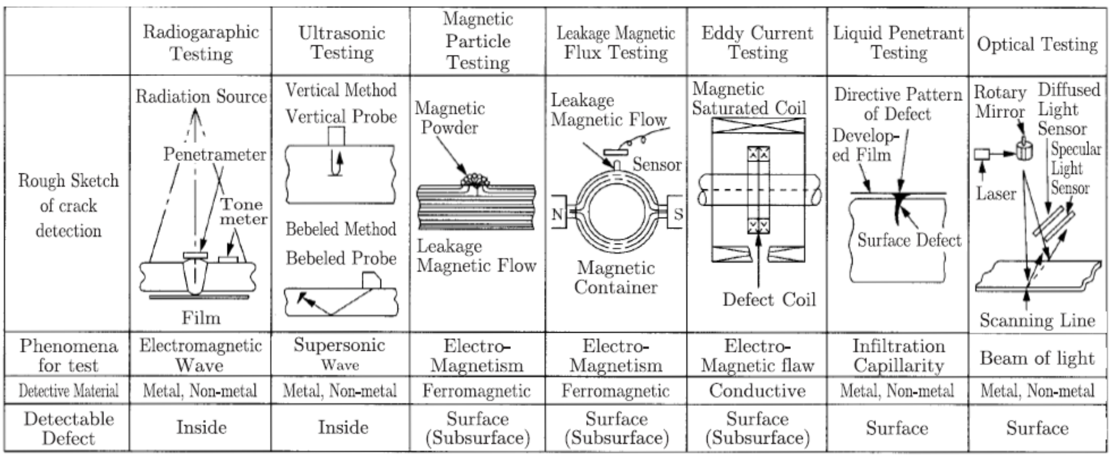


Fig. 6. Comparison of non-destructive tests [68]

8.1.8. Fractures caused by wrong production and heat treatment

The reason for failure in engineering component can be attributed to design deficiencies, poor selection of materials, defects in manufacturing, exceed the limitation of design, overloading, and inadequate maintenance etc**.** Fracture can be caused due to improper heat treatment [69]. The uniformity of the distribution of the heat in a heat treatment process also plays a major role in the fracture caused by wrong heat treatment. Metallography and fracture toughness could be related to heat treating issues. Improper heat treatments may cause hydrogen embrittlement, decarburization etc., which are detrimental to the specimen and may cause fracture. The steel's toughness is affected by changes in tempering temperature [70].

8.1.9. Maintenance of Springs

Normally springs don't need any special maintenance since there will be no presence of wear or deterioration when they're well designed and properly manufactured. The only requirement is that during the spring service it should be inspected and maintained for corrosion. In cases where the springs are designed based on peak stresses that are nearest to the endurance limits and also if there are variables like inclusions on the component, stress flaws, and other stress raisers, there is a possibility that fatigue fracture may occur during service. In components, which show a history of spring failures, periodical visual inspections for various defects of the surface and dye penetrant tests for minute cracks help in detecting failure so that they could be prevented. It should be considered that once the testes have been done the component should be cleaned and coated with oil to prevent corrosion. If cracks are detected on the part's surface, the best form of action that should be taken is to complete replace the necessary springs. It is impossible for springs with hair line fracture to be repaired or reclaimed [71].

9. Testing used for furniture springs

All testing of furniture is carried out under the European standard BS EN 1725: 1998. This European standard had been prepared to provide assurance that the domestic furniture complying with the requirements are safe. It is intended for the prevention of injuries through normal functional use.

This European standard describes the requirements for mechanical safety and testing of all types of furniture components.

The testing of the furniture springs is done using impactors etc. The springs will undergo pulsating load test with different load changes, the parameters were determined before and after the load tests. Drop weights to simulate a person dropping on the bed could be used to see as to how many cycles the springs can withstand before failure.

Fig. 7. Zigzag Spring tester

10. General specimen preparation method

Below described is the general specimen preparation method.

10.1. Sampling and Embedding

Lateral, longitudinal cross-sectional etc., adjustments should be made during the removal and preparation of the metallographic samples for the investigation [72] and exposure to high heat and deformations should be avoided to stop any occurrence of structural changes [72,73]. Any present standardized separation method can be used to separate a sample from a metallic component [73].

It is mandatory, the specimen be removed using unique cutting devices that work on the principle of plunge grinding.

Here, the component is then fastened and the cut is made with the help of a rotary disc. The disc material to be used is dependent on the material that is to be cut. Also, spark-erosive cutting, also called electrical discharge machining (EDM), is ideal.

To enhance the handling of the obtained sample after cutting, the samples are embedded into hot or cold plastics, which depends on the dimensions of the specimen and also the usage of the specimen [73].

When considering cold mounting, basically two compounds are used, an un-cross-linked polymer and an activator are used, they are mixed to create a fluid or paste and is coated over the sample, which is placed in molds used for embedding specimens, where the mounting medium polymerizes and thickens. The benefit of cold mounting is the faster application of the specimen into the mold and is lesser costs. While in hot mounting or embedding, the sample is inserted into special mounting presses, because of the usage of high temperatures and pressures the specimen and the plastic granules around the specimen get fused. The only pros of this method are the improved bonding between the specimen and the mounting medium. In both of the methods, the finished product is the same, resulting in a cylindrical, easily handled specimen.

Unique types of specimen removal techniques for TEM (transmission electron microscope) studies are needed and invoke a special case. As the specimens for TEM are needed to be extremely thin at hundred nanometers (100 nm), unique processes are applied to permit increased thinning of the material. At present, the FIB method (focused ion beam) is playing a major role, where a focused ion beam is used in cutting resulting in thin lamellae [74, 43].

10.2. Grinding and Polishing

To improve the visibility of the grain structure, a highly smooth, polished surface is of requirement. Firstly, the depth of the abnormal surface layer (i.e. influence of temperature or plastically deformation at specimen removal) is reduced by slowly grinding it until the true structure is visible [72, 73,75].

The sample is then usually ground with an aluminum oxide abrasive paper (Al_2O_3) on a rotating disc. The sequence of sand papers is customarily in the series of grits 180, 240, 320, 400, 600, 800 and 1000.

The magnitude of the number stands for the purity of the grain, not the grain size. It is defined by the amount of meshes per square inch screening surface when screening the abrasive material.

After each grind, the specimen is removed of any impurities and is rotated along 90° and is further ground in the same direction. This is done so that the grinded grooves formed from the previously used paper is removed completely.

Due to modern advancements in the metallographic grinding device, there isn’t any need for manually pressing the specimen against the paper during grinding, now a day the samples are held using special instruments which also take care of rotating the specimen.

There are fully automatic or semi-automatic grinding devices at present which are able to execute every task from grinding and polishing to cleaning autonomously.

Polishing is done to eliminate the grinding grooves which are found after the process of grinding.

Polishing agents like diamond paste or diamond suspension (having a grain size of 15, 6, 3, 1 lm) are applied using a velvet or woolen cloth [73, 76]. Formerly, de-mudded aluminum oxide (Al_2O_3), green rouge (chromium oxide) (Cr_2O_3) and other abrasive substances were utilized.

10.3. Etching

Etching is the procedure of using the corrosive nature of an acid or a chemical to produce designs or shapes on the material, in this instance, etching is done so that the structure of the material is clearly visible under a microscope. The traditional or commonly used etching technique is the dip etching. It uses different chemical etching agents that act with different intensities on various structural components. The difference between macro etching and micro etching is that the use of macro etching is to provide a complete synopsis of the segregations and the primary structures. The magnifications involved in such evaluations are in the area of 1:1–30:1.

In the investigation of micro etched surfaces, magnifications of 50:1–1,000:1 is used. The intent of micro etching is to develop the microstructure.

The information concerning macro etching is explained as follows since they see normal usage in forming technologies. The most well-known macro etching technique is ‘‘Oberhofer etching’’, where the sample is kept at ambient temperature inside an etching agent made of distilled water, ethanol (96 %), HCl (32 %), Cu(II) chloride, Fe(III) chloride and Sn (II) chloride [73].

In this etching method, the segregation free region will appear dark, while segregation regions will be unaltered. By the use of this method, the ‘‘fiber structure’’ of a specimen becomes increasingly visible, making it captivating for forming engineers.

Components like screws, crank shafts etc., shows an uninterrupted fiber like flow and because they are much more affected by stress than any other components that were produced by machining because of their discontinuous fiber structure.

10.4. Metallography

Metallography is the investigation of structural and mechanical properties of materials. Structural investigation permits us to determine the different properties of the materials such as physical, mechanical, and chemical.

Microscopic analytical methods are used during the development, quality control and manufacturing of the forming components and also to find the cause of failure or damage of such components. The grain structure has a number of various characteristics namely their size, shape, distribution and volumetric content of the phases. The assessment of the structure provides the vital data on the phase boundaries, segregations, precipitations, lattice defects, grain size distribution, deformation structures and their recrystallization and regeneration. The data on the cracks, pores, and other such defects can also be acquired.

11. Experimental

This section consists of the experimental part or the thesis.

11.1. Material used for springs

Since the project is on upholstery spring. The material used in the experiment is EN 10270 according to the European standard, the spring wire shall be made from steel corresponding to EN 10016-1, EN 10016-2 and EN 10016-4.

11.1.1. Chemical Composition

The upholstery springs of this type was made from spring wire produced with the chemical range shown in table. Chemical composition and processing may vary according to its use.

C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cu [%]
0.830	0.190	0.660	0.012	0.010	0.031
Ni[%]	Cr [%]	Mo [%]	Al [%]	N [%]	
0.010	0.040	0.005	0.003	0.003	

Table 4. Chemical composition

The addition of micro-alloying elements can be agreed between the manufacturer and the purchaser. Since some diameter ranges of the steel require some attention to residuals, no figures are mentioned for chromium, nickel, molybdenum, tin, etc.

Thus, leaving the purchasers to make special arrangement with the supplier, dependent on their supplier on their mutual processing conditions. This is also the case for aluminum content.

11.1.2. Similar International Standard

ASTM	India Standard	JIS	Chinese	ISO
ASTM A417 ASTM A407	IS7864-2	JIS G 3521	YB/T 5220-93	ISO 8458-2: 2002

Table 5. Similar International Standards

The standards shown are upholstery springs used in the manufacture of automotive seats, furniture springs, bed spring units, mattresses, furniture cushions etc. These types of wires are not intended for manufacturing mechanical springs.

The spring wire received was phosphate coated and were patented and cold drawn.

11.2. Microscopy analysis of spring steel

The microscopic analysis of the specimen consists of the following procedures as stated below

11.2.1. Specimen Preparation

The removal and preparation of the specimen should be done such that there are no structural changes resulting from deformation or excessive heat. To improve handling, they were embedded in plastic.

11.2.2. Grinding and Polishing

Grinding is done so that the grain structures are visible. A well ground surface layer is normally required which is done by gradually grinding the surface until the actual structure is recognizable.

The specimen was ground using abrasive paper of 200,600,800,1000,1500,2000,2500 microns respectively using SMART LAM 2.0 Lam plan grinding machine as shown in fig.6,6.1. Polishing is done to remove any groves found due to grinding. A diamond suspension of 1 micron was used to polish the surface.

Fig.8. SMART LAM 2.0 - LAM PLAN

Fig.9. SMART LAM 2.0 - LAM PLAN HEAD

11.2.3. Etching

Etching was done to improve and highlight the features of metallography, a 3.5 % of nital was used in etching.

11.2.4. Metallography

The metallography of the specimen was done using a Nikon eclipse LV 100 ND shown in fig.9., with a high definition camera head DS-Ri 2 from Nikon and CFI60-2 objective with magnification of 20X/0.45 A, 50X/0.80 A and 100X/0.90 A.

Fig.10.Nikon Eclipse LV 100ND

The microstructures were captured using the software NIS- Element D which delivers color documentation capabilities that include basic measuring and reporting. The following are the microstructures taken of the specimen.

11.3. Tensile testing

The test was performed using the tensile testing machine, in which the specimens were help together by a clamp and was subjected to controlled tension until failure. The data from the experiment was transferred to catman express software in the computer through a spider 8 converter, the obtained data were as follows time device s, Force kn, and displacement, mm. From the obtained data, the calculation for stress was done using the formula

Stress=Force/Area or σ=F/A

Where $A = \pi r^2$ and r was taken to be 1.9 mm

The percentage of deformation was also calculated using the formula

Deformation =Displacement/Initial length or (Δl/l)*100%

Where the initial length (l) was taken to be 100mm

From the obtained results the required tensile strength, Rm and 0.2% offset yield strength, Rp was calculated for each specimen. The tensile strength is the maximum amount of stress obtained from the logged data.

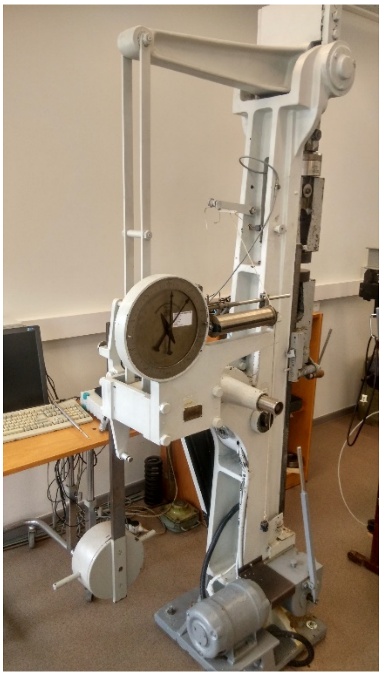
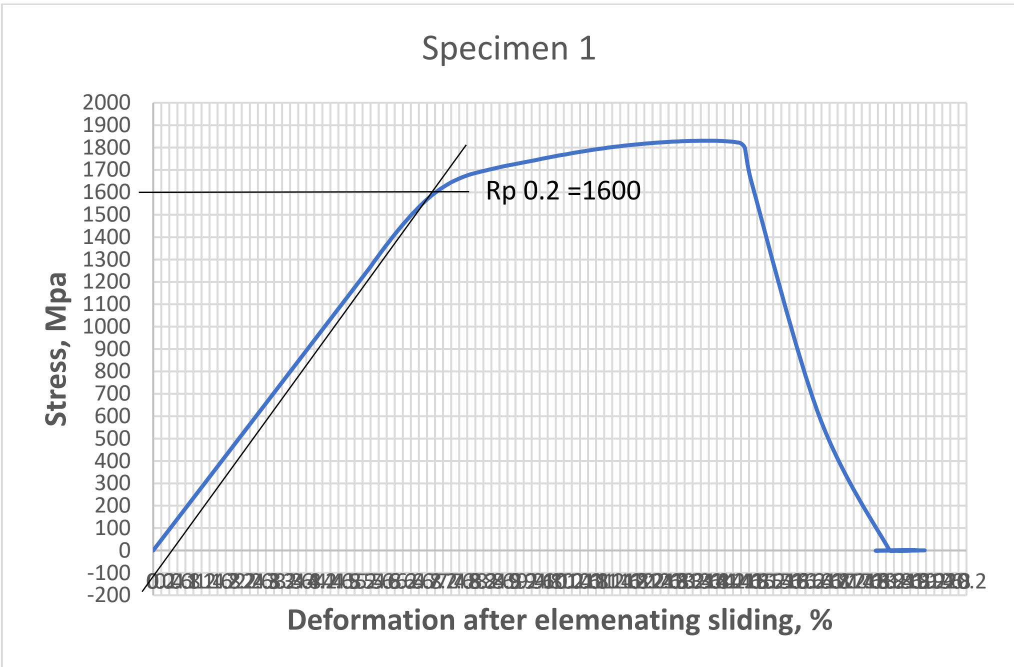


Fig.11. Universal testing machine

The following graph shows how the 0.2% offset yield strength was obtained by drawing a linear 0.2% offset line and by drawing a horizontal line at the point where the 0.2% offset line intersects.



The tensile strength and 0.2% offset yield strength has been found out for every specimen.

11.4. Tempering

Present day trends in the metal industry are towards improving the surface properties (e.g. corrosion and wear resistance) of materials. Alloying and heat treatment are very useful tools to improve the matrix properties against corrosion or wear. Tempering is done to improve the toughness and to reduce some of the excess hardness. The process is done by heating the metal to some point below the critical point for a period of time. The specimens were tempered at the temperatures and time as shown in the table 7 below.

Tempering temperatures, ^{O}C	Duration, min
175	120,90
200	120,90
250	90,60,30
275	60,30,20
300	60,30,20
320	45,30,15
350	30,20,10

Table 6. Temperature and duration of tempering

It is common and long-time knowledge that steel heated in contact with air at temperatures in the tempering range takes on various temper colors due to the formation of a thin oxide film. As an example, the 1948 ASM

Metals Handbook gives the following table 8

Heating Temperature	Color
400°F or 205°C	Faint Straw
440°F or 225°C	Straw
475°F or 246°C	Deep Straw
520°F or 271°C	Bronze
540°F or 282°C	Peacock
590°F or 310°C	Full blue
640°F or 338°C	Light blue

Table 7. Heating temperature and Colors

The specimens were of the following colors after tempering as shown in the picture fig.12.

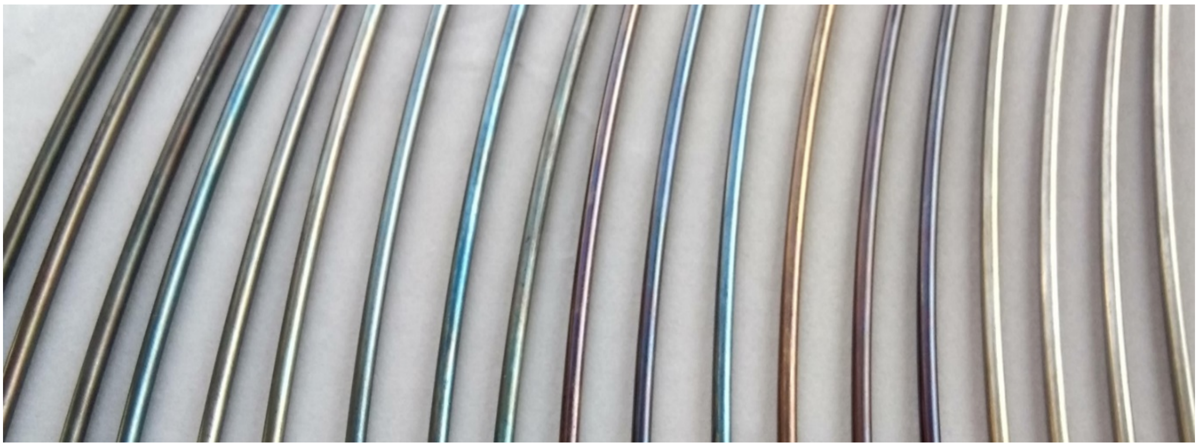


Fig.12. Different color specimen after tempering

12. Results and discussion

12.1. Investigation of surface and microstructural defects of spring steel

The specimens were investigated for surface and microstructural defects. The surface defects test was carried out according to EN 10218-1.

12.1.1. Decarburization

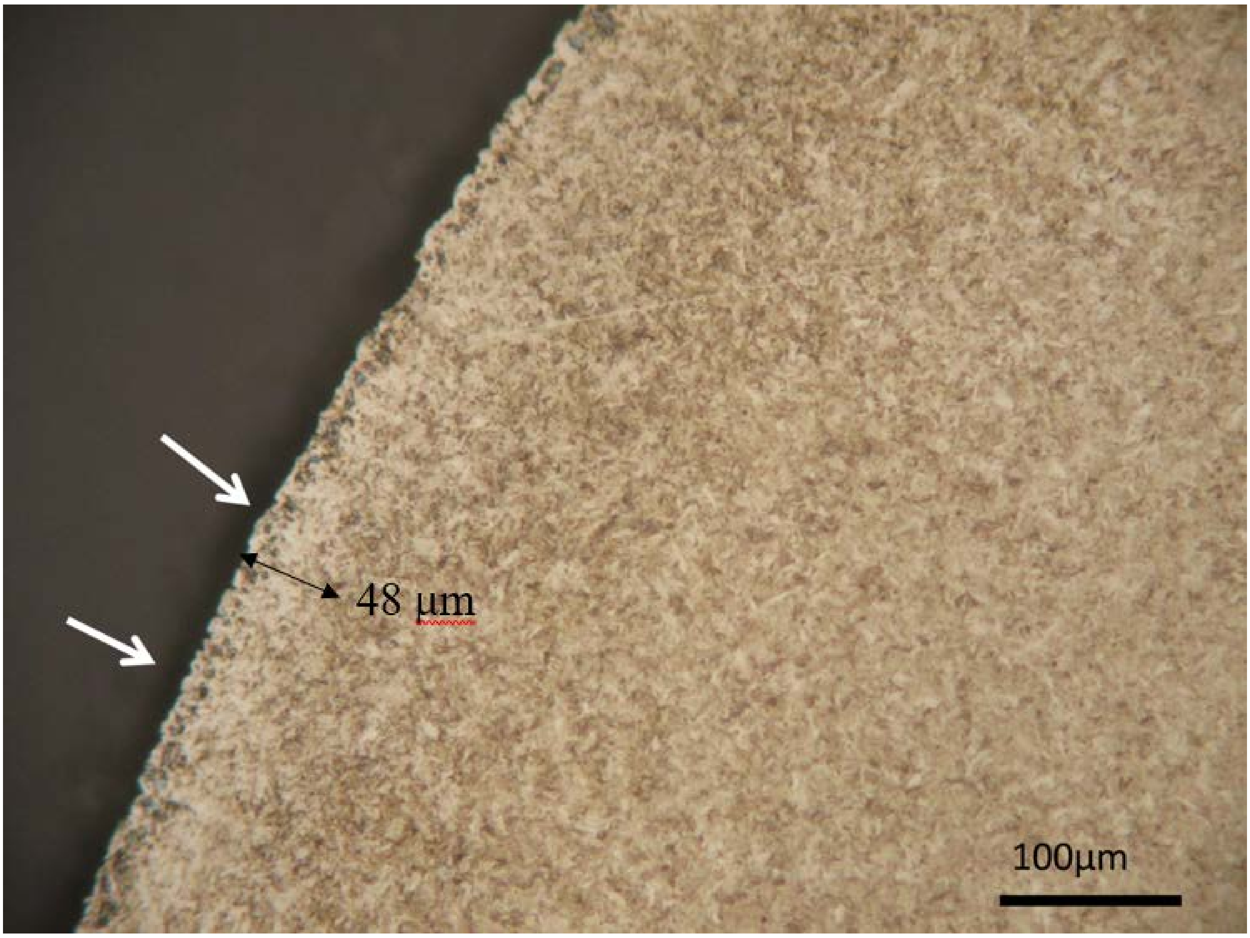


Fig.13. Decarburization seen in the specimen

Decarburization occurs when carbon atoms at the steel surface interact with the furnace atmosphere and are removed from the steel as a gaseous phase. Decarburization is detrimental to the wear life and fatigue life of steel heat-treated components.

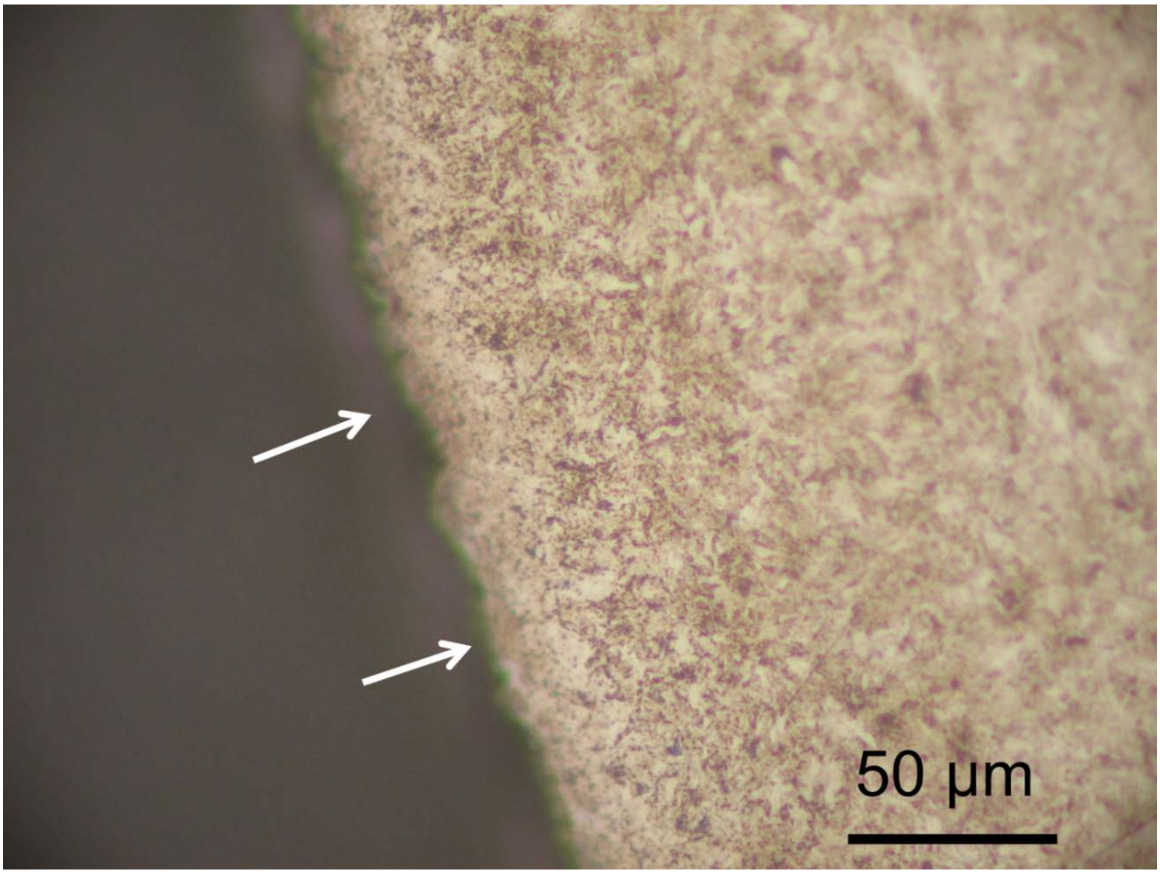


Fig.14. Decarburization

Decarburization was inspected by microscope in accordance to EU 104 on a transverse metallographic test piece. According to EN10270-1 the permissible decarburization depth for wire was 1.5% max of wire diameter. The wire diameter is 3.80 mm, from this we can find the depth of deformation to be 1.5% of 3.8 mm= 0.057, Therefore 1.9 mm= 0.0285 mm, which is approximately 30 micrometers. But the obtained depth of decarburization using a micrometer was 48 micrometers. Which is higher than the permissible depth of decarburization? Therefore, decarburization may also be a reason for the failure of the specimen.

12.1.2. Non-metallic inclusions

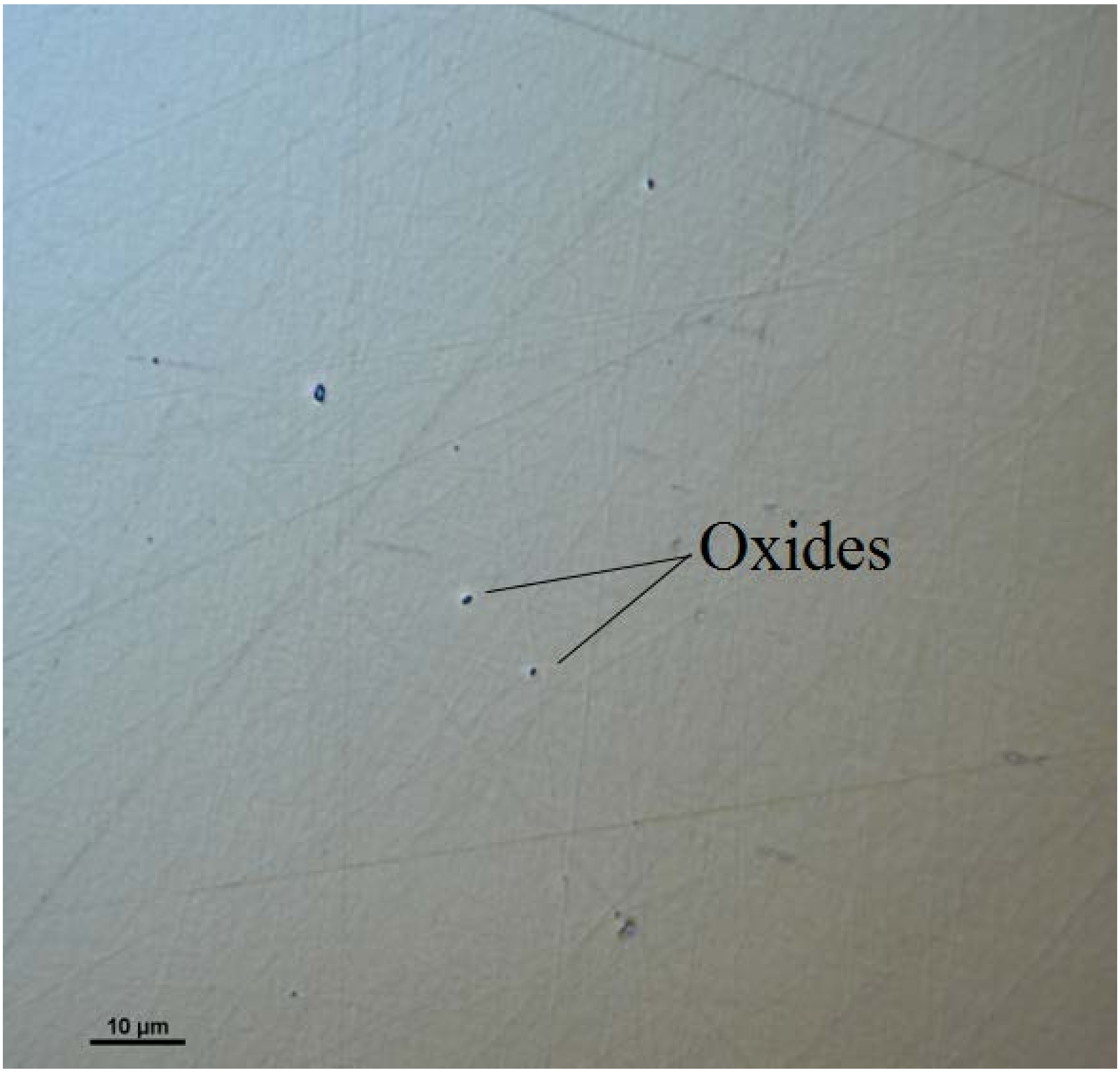


Fig.15. Non-Metallic Inclusions Oxides

Few oxides were found, which were very small in amount and cannot disturb the strength of the specimen, according to the standard scale it was the smallest, so it is not a reason for the failure of the specimen.

12.1.3. Surface defects

There were no cracks or any other surface defects seen in the specimens but surface roughness was present.

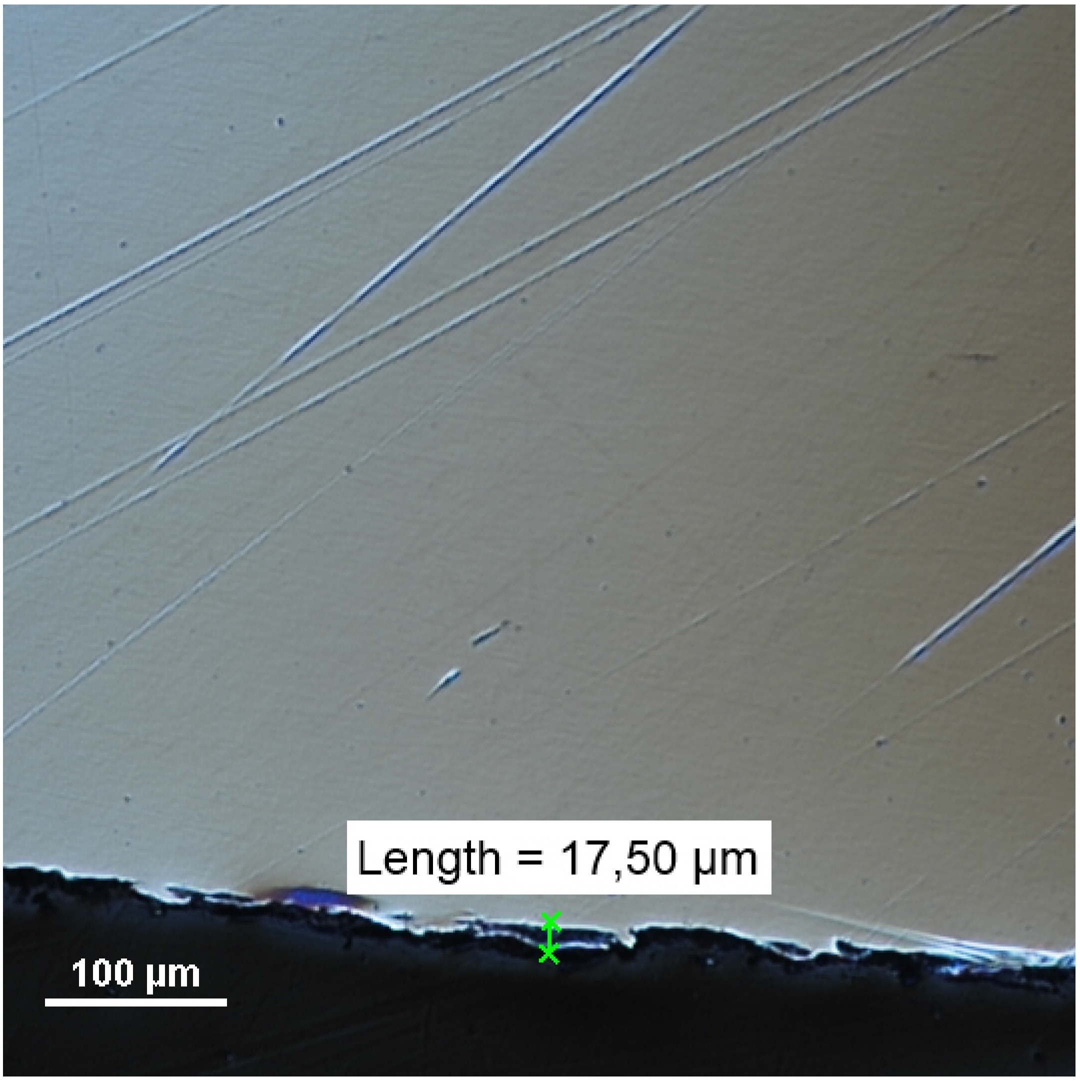


Fig.16. Surface Roughness

The permissible depth of surface defects is 1% max. of the wire diameter; this is taken from the European standard 10270-1.

Therefore 1% of 3.80mm= 0.038mm which is equal to 30 µm

Then 1% of 1.90mm=0.019mm which is equal to 19 µm

The roughness is within the permissible limit. But might cause failure.

12.2. Microstructural analysis of spring steel

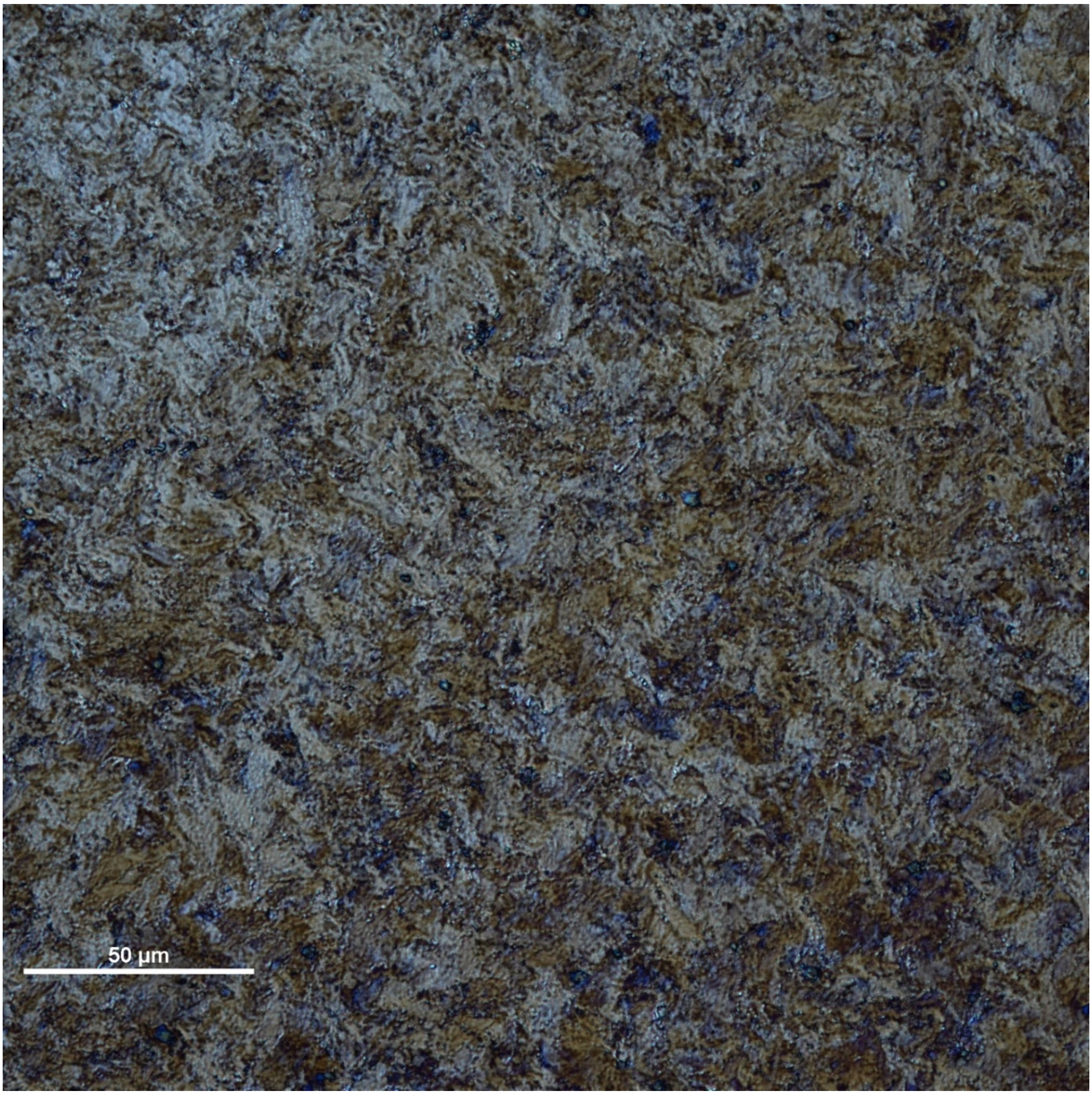


Fig.17. Cross section

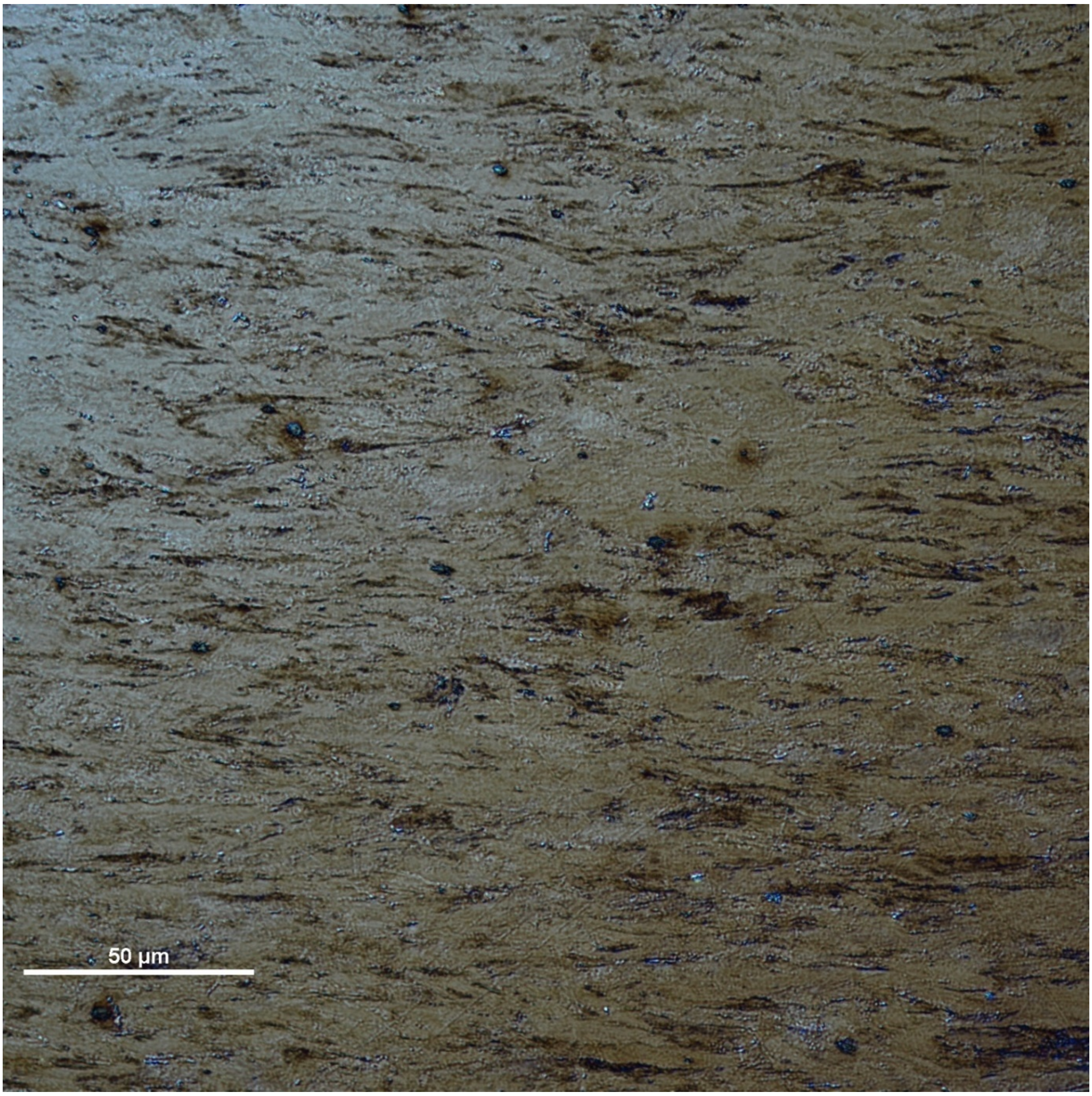


Fig.18. Parallel

Fine fibrous microstructure is observed, which are the typical microstructure seen in Furniture spring steel.

12.3. Determination of tempering temperature of spring steel samples

The determination of tempering temperature of spring steel was done as follows

12.3.1. Comparison between tempered specimen in company and in laboratory

Tempered specimens in lab

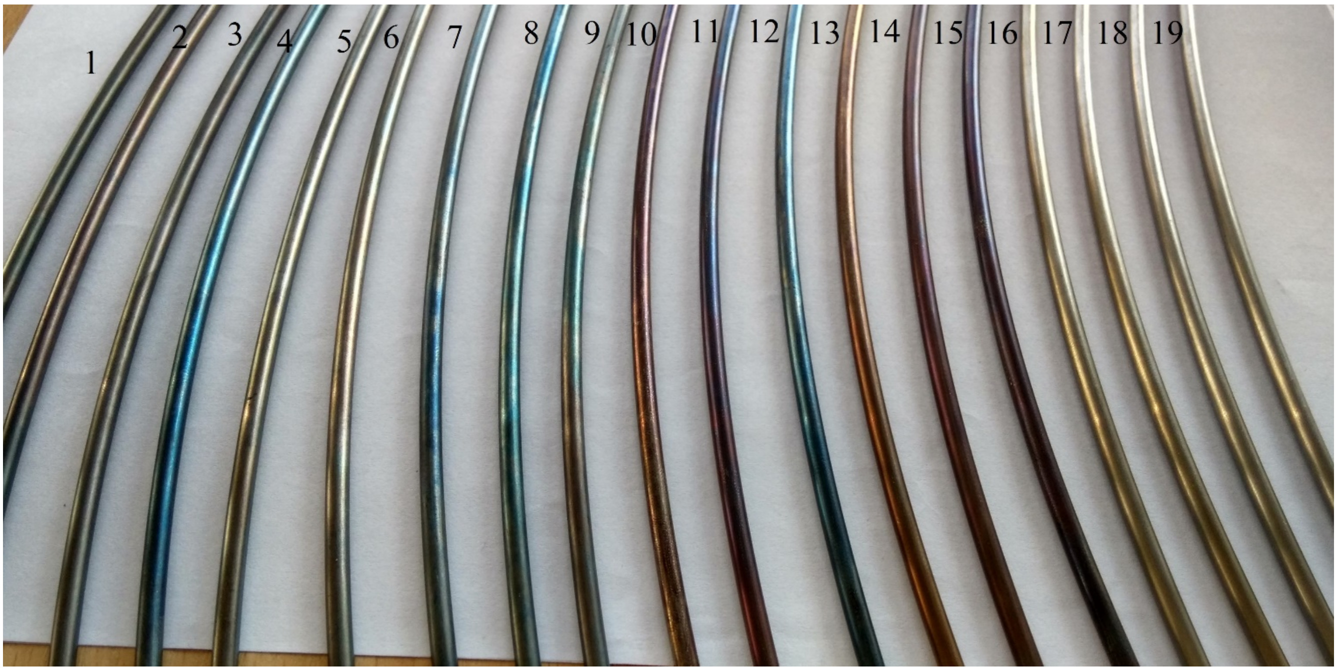


Fig.19. Specimens tempered in lab

S.no	Tempering temperatures, ^{O}C	Specimen no.	Duration, min
1.	175	19,18	120,90
2.	200	17,16	120,90
3.	250	15,14,13	90,60,30
4.	275	12,11,10	60,30,20
5.	300	9,8,7	60,30,20
6.	320	6,5,4	45,30,15
7.	350	3,2,1	30,20,10

Table.8. Tempering temperatures and duration of different specimens

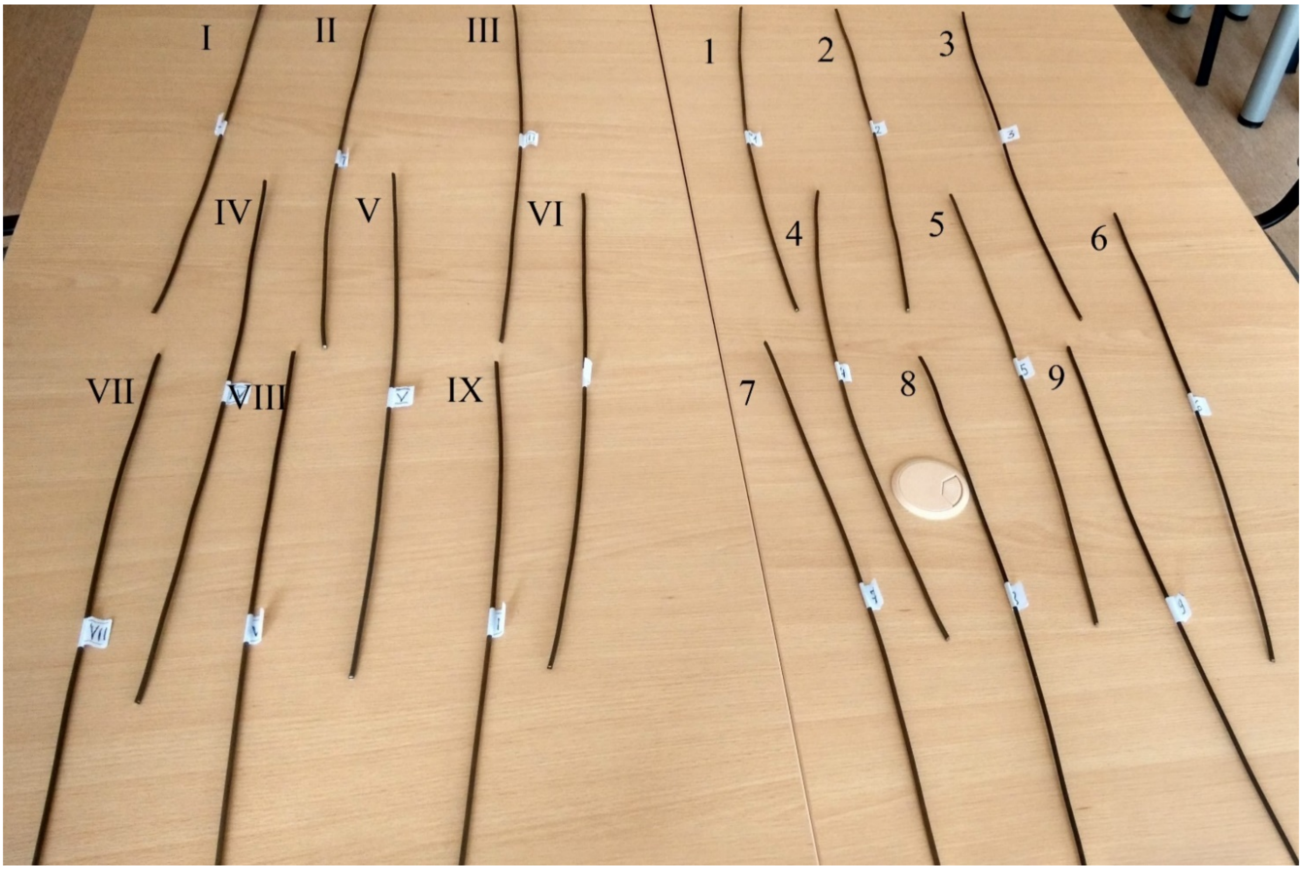


Fig.20. Position of the specimens in oven which were tempered in company

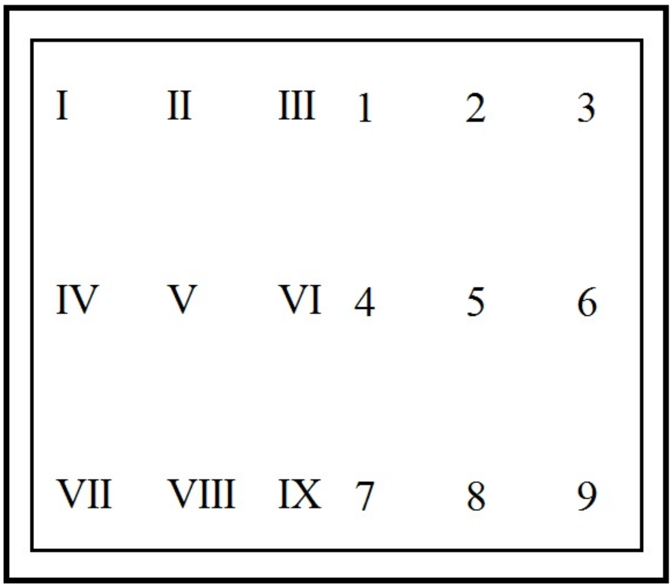


Fig.21. Schematic of position of the specimens in the oven

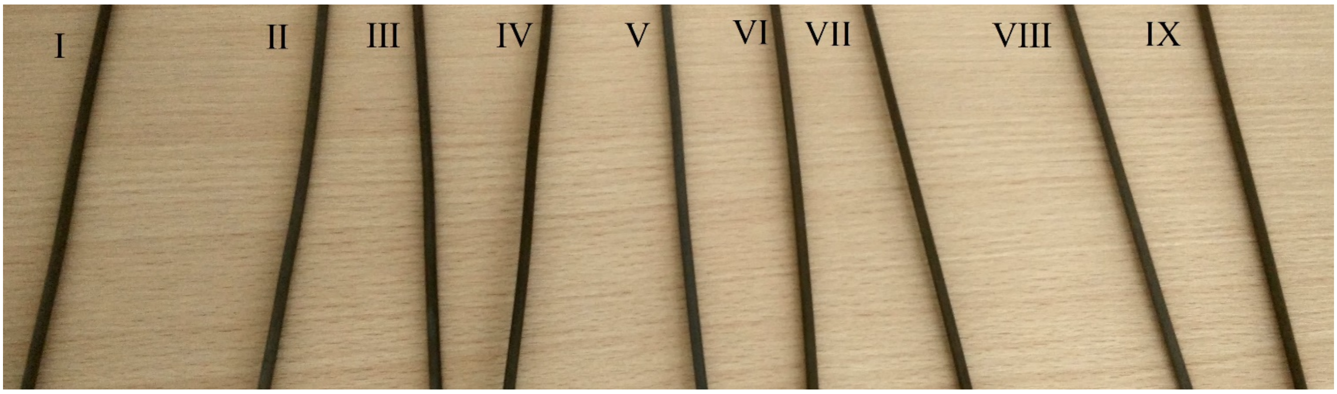


Fig.22. Tempered color of specimen tempered in company

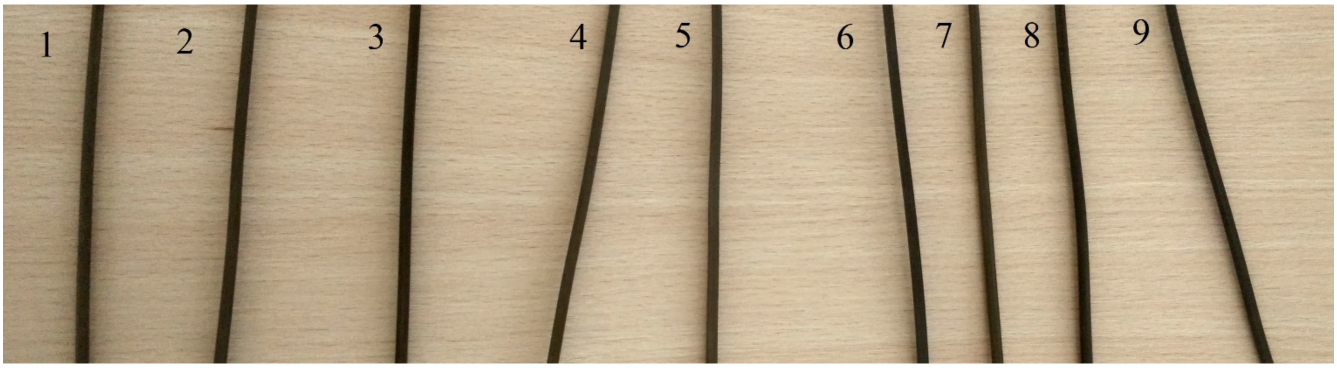


Fig.23. Tempered color of specimen tempered in company

Color comparison of specimen tempered in company to specimen tempered in lab

Specimen tempered in company	Specimen tempered in lab	Specimen tempered in company	Specimen tempered in lab
I	16	1	17
II	16	2	17
III	16	3	9
IV	6	4	16
V	1	5	17
VI	16	6	2
VII	16	7	17
VIII	2	8	15
IX	5	9	15

Table.9. Color comparison between specimens tempered in lab and company

From the comparison of the tempering colors of the specimens it can be found that the specimens in the company were not tempered properly since their color varied stating they were not tempered at a constant temperature.

12.4. Investigation of mechanical properties of spring steel

Tensile testing results

The tensile test was carried out according to EN 10002-1 and yielded the following results

S. No	Regime of tempering	Tensile strength, Rm	0.2% offset Yield Strength, Rp	Rp0.2/Rm*100%
1.	Regime of tempering 1	1830	1600	87.43169
2.	Regime of tempering 2	1796.45	1535.85	85.49361
3.	Regime of tempering 3	1800.68	1498.70	83.22967
4.	Regime of tempering 4	1830.319	1610.71	88.0016
5.	Regime of tempering 5	1825.56	1614.42	88.43423
6.	Regime of tempering 6	1831.91	1558.09	85.05276
7.	Regime of tempering 7	1838.25	1700	92.47926
8.	Regime of tempering 8	1846.72	1662.57	90.02827
9.	Regime of tempering 9	1819.206	1549.24	85.16023
10.	Regime of tempering 10	1845.13	1714.82	92.93762
11.	Regime of tempering 11	1854.66	1709.67	92.18239
12.	Regime of tempering 12	1853.60	1733.84	93.53906
13.	Regime of tempering 13	1874.23	1722.37	91.89747
14.	Regime of tempering 14	1872.65	1714.96	91.57931
15.	Regime of tempering 15	1857.39	1700	91.52628
16.	Regime of tempering 16	1871.06	1686.91	90.15799
17.	Regime of tempering 17	1889.58	1776.34	94.00713
18.	Regime of tempering 18	1880.58	1856.77	98.7339
19.	Regime of tempering 19	1893.28	1863.12	98.407

Table 10. Tensile Testing Results

The Tensile strength was found to be within the range as indicated in the specification EN 10270-1. The regime of tempering $R_{p\,0.2}/R_m$ *100% was within the required range of being over 85% [77].

13. Recommendations for development of production and heat treatment of furniture steel springs

Smaller load may be applied to the furnace such that there is a lot of gap between the springs and the heating done will be even throughout the furnace since there is even circulation of air and even heat distribution.

From the comparison between the tempering regime of the specimens tempered in the lab and company, we are able to conclude that the specimens were not properly tempered in the company thus leading to their failure. This can be avoided by installing new tempering furnaces, as new advanced furnaces have inbuilt technology which monitor the proper tempering of the specimens.

Decarburization can be completely controlled during the patenting and cold drawing process itself.

14. Conclusion

From investigation of the mechanical properties of spring. We can conclude that the failure was caused because of improper tempering of the specimens in the company and may also be due to decarburization seen in a few specimens, can also be caused due to surface roughness which was present in few of the tested specimens. the company should improve their tempering techniques by installing new and advanced furnaces so that the quality of the furniture springs will not be compromised and also find ways to control the amount of decarburization or by removing decarburization totally.

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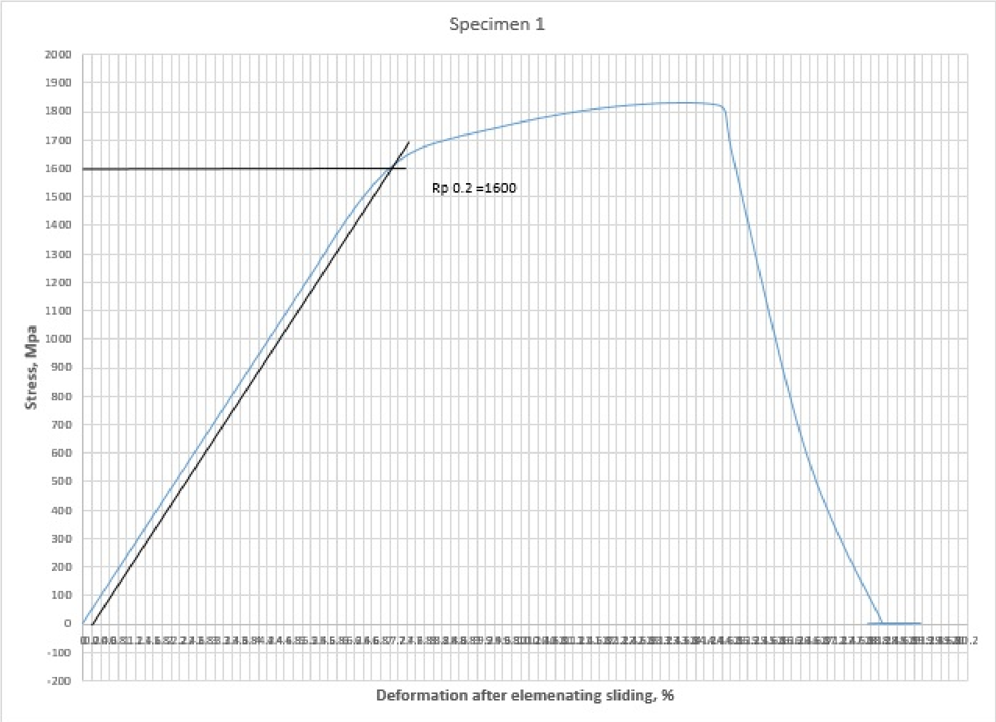
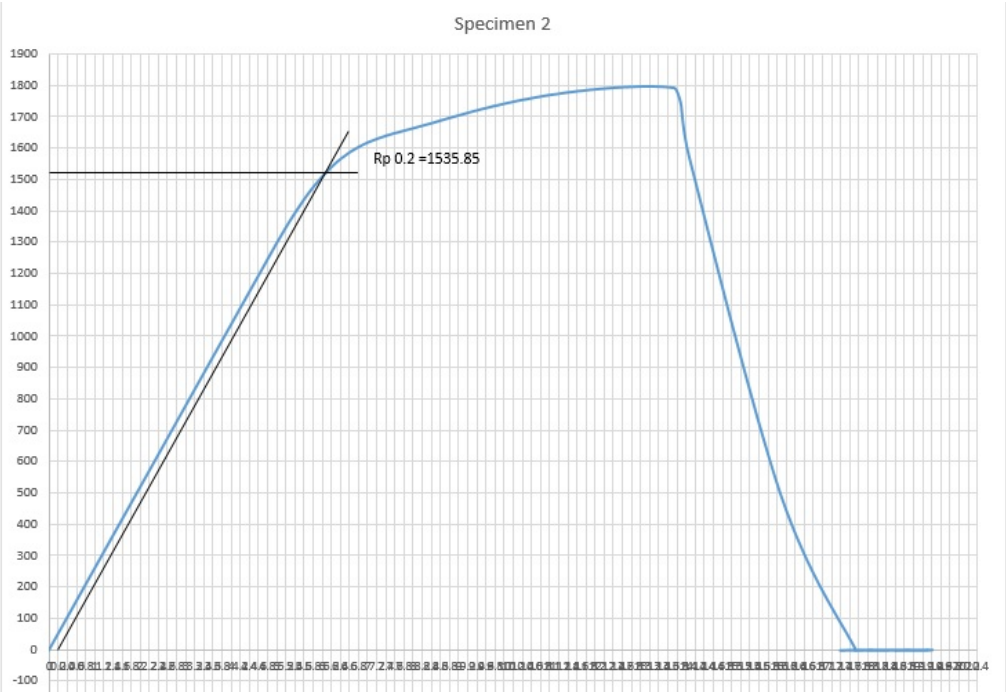
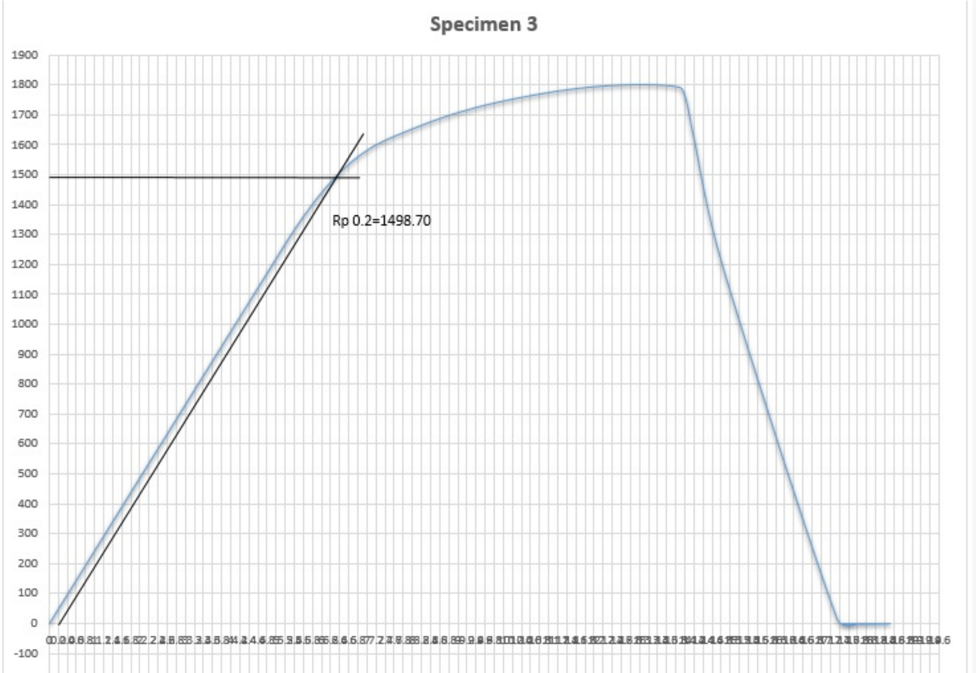
16. Appendices



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1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
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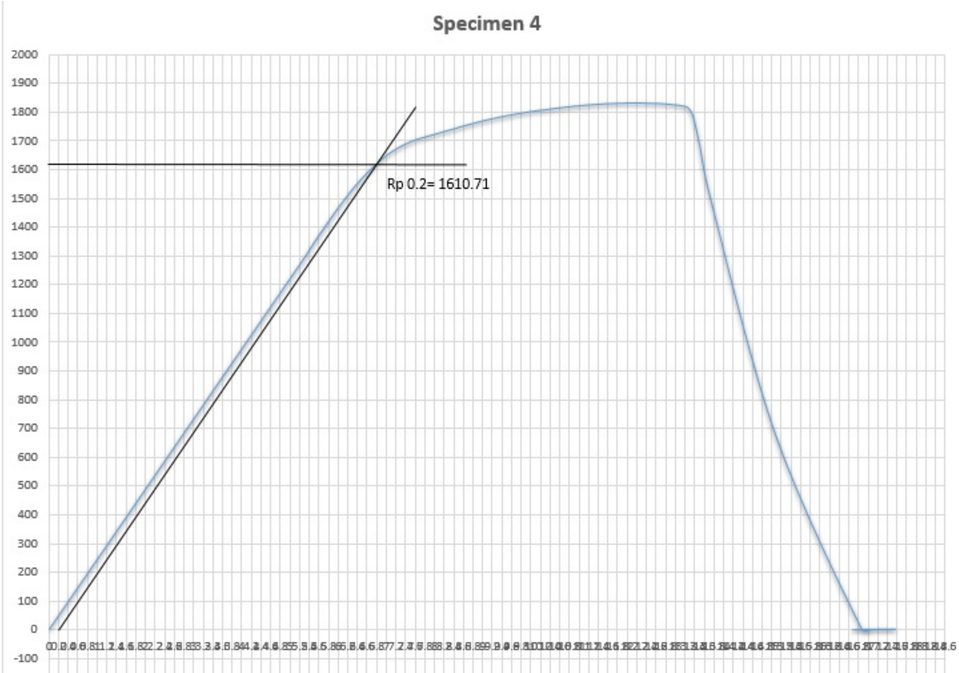
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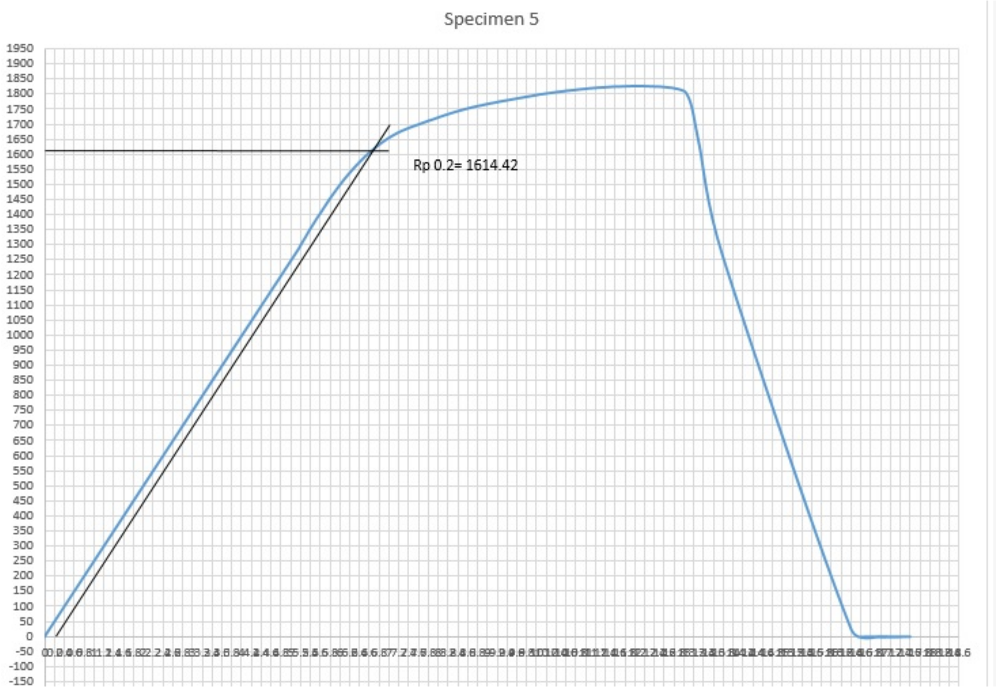
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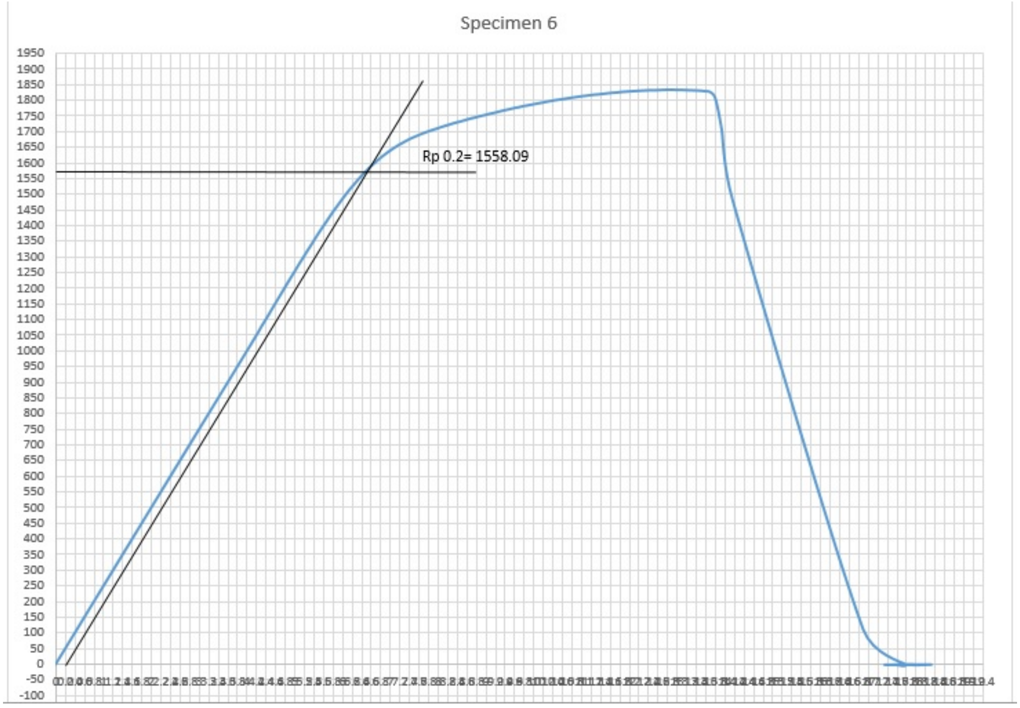
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