Politecnico di Milano

Scuola di Ingegneria Industriale e dell'Informazione

LAUREA MAGISTRALE
INGEGNERIA DEI MATERIALI E
DELLE NANOTECNOLOGIE
MASTER OF SCIENCE IN MATERIALS ENGINEERING AND NANOTECHNOLOGY

Chemical and Mechanical Analysis of the various steel grades tubes

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Anno Accademico 2012-2013

Sommario

Abstract

The purpose of this work is to investigate Mechanical behavior of different steel grade tubes by the effect of heat treatment. Structural and mechanical properties of high strength steel tubes of various diameter and wall thickness are presented in this paper. The results of tensile testing shows intensive increase in the ductility at high temperatures while strength decreasing with tempering temperatures.

Abstract (Italian)

Lo scopo di questo lavoro è quello di studiare il comportamento meccanico dei tubi di acciaio diversi per effetto del trattamento termico sulle Proprietà strutturali e meccaniche di tubi d'acciaio ad alta resistenza di vario diametro e spessore della parete sono presentati in questo documento. I risultati delle prove di trazione mostrano un aumento di duttilità a seguito di trattamenti ad alte temperature, mentre la resistenza meccanica decresce con la temperatura di rinvenimento.

Preface

This report is the documentation of final thesis submitted for the degree of Master of

Materials Engineering & Nanotechnology. The stage has been carried out with

the cooperation of Professor Luca Nobili Giampaolo (Politecnico di Milano), Department of

Dipartimento Di Chimica, Materiali E Ingegneria Chimica Giulio Natta and Company Marcegaglia SPA at Lomagna Plant (LC)

All the technical and practical detail has been provided by Marcegaglia SPA Company, with the instructional

And reading solutions from Professor Luca Nobili Giampaolo and Engineer Davide Galbiati.

Acknowledgements

After the almighty Allah, I would like to thank our supervisors at both ends, i.e. Professor

Luca Nobili Giampaolo (Politecnico di Milano), Engr. Davide Galbiati (Marcegaglia SPA)
For great guidance and help.
I would also like to pay our heartedly gratitude to the Head of Marcegaglia SPA Lomagna Plant

For trusting and believing in me and providing us with an opportunity to gain the

Technical and practical experience in my desired metalwork field.

I would like to thank Mr Sala Anselmo & Marco Alessio for

Providing the necessary help, training, feedback and availability to handle the matter and to
Understand the technical complexity.

Introduction:

The training project session was carried out at Marcegaglia SPA., particularly this training period took place at Marcegaglia Lomagna plant.

The Marcegaglia plant in Lomagna (Lecco) is dedicated to the manufacturing of high-frequency welded tubes from hot-rolled pickled strip, cold-rolled strip and coated (aluminized and galvanized) for sectors such as: automotive, furniture, toys, bicycle ,motorcycle, heating, roller conveyors, and construction.

To fulfill the customers demand and to attain the minimum requirements as indicated by the clients, Lomagna has an internal laboratory where chemical and mechanical tests are performed for the final product (tube), results are also reported in the certificates that the customer receive with the tubes delivery.

I got all the basics of my job activities from my tutor Engineer Davide Galbiati at Lomagna Plant and started work on the data of already produced tubes.

The purpose of this thesis is to collect data from the different production machines of different tubes in order to test them for the specific properties containing both chemical and mechanical analysis and to get the Characteristics of the tubes for both future and present use, and to give easy report to quality office to answer to the several question posed by commercial side about feasibility of tubes and the possibility to guarantee their behavior during mechanical manipulation, especially with the new products and new customers.

Main focus of this thesis will to check difference from the point view of mechanical behavior between same steel grade materials produced in different way.

1. Standards of production

In European region standard reference for precision tube production is EN 10305, this document gives nomenclature to the product quality range and minimum requirement to fulfill.

Family of EN 10305 group different kind of tubes as follows:

- Part 1 : Seamless cold drawn tubes.
- Part 2: Welded cold drawn tubes.
- Part 3: welded cold sized tubes.
- Part 4: seamless cold drawn tubes for hydraulic and pneumatic power system.
- Part 5: Welded and cold sized square and rectangular tubes.
- Part 6: welded cold drawn tubes for hydraulic and pneumatic power system.

For Marcegaglia Lomagna production it is used part 3 (precision tube in round shape) and part 5 (precision tube in square and rectangular shape).

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 10305-3

January 2010

ICS 77.140.75

Supersedes EN 10305-3:2002

English Version

Steel tubes for precision applications - Technical delivery conditions - Part 3: Welded cold sized tubes

Scope:

This European standard specifies the technical delivery conditions for the welded cold sized steel tubes of circular cross section for the precision application with specified outside diameter 193,7mm.

Tubes according to this document are characterized by having precisely defined tolerances on dimensions and a specified maximum surface roughness.

Tube production and delivery conditions of EN 10305 Standards:

Possible surface conditions are:

- a)S1 (black);
- b)S2 (Pickled);
- c) S3 (cold rolled);
- d) S4 (Coated to an agreed condition);

§2.4- Tubes made of the steel grades E155, E195, E235, E275, E355 shall be supplied in the delivery condition +CR1 or +A or +N(see table). Tubes made of the grades E190, E220, E260, E320, E370 and E420 shall be supplied in the delivery condition +CR2

§2.4-All non-destructive testing (NDT) activities shall be carried out by the qualified and competent level 1,2,3 personnel authorized to operate by the employer.

The qualification shall be in accordance with EN 10256 or , at least , an equivalent to it.

It is recommended that the level 3 personnel be certified in accordance with EN473 or at least an equivalent to it.

The operating authorization issued by the employer shall be in the accordance with a written procedure. NDT operations shall be authorized by a level 3 NDT individual approved by the employer.

Designation	Symbol [(a)]	Description
Welded &cold sized	+CR1	Normally is not heat treated, but suitable for final annealing. [(b)]
	+CR2	Not intended for heat treatment after the welding and sizing. [(c)]
Soft Annealed	+A	After welding and sizing the tubes are annealed in a controlled atmosphere
Normalized	+N	After welding and sizing the tubes are normalized in a controlled atmosphere

a- In accordance with EN 10027-1

b -After annealing or normalizing the resulting mechanical properties meet the requirements specified in table 4 for the delivery conditions +A or +N respectively.

c- If further heat treatment is applied, the resulting mechanical properties may be outside the specified requirements.

Table 1 – Table 1 of EN 10305-3

Chemical composition analysis[a]:

Steel Grade		In % by mass					
Steel name	Steel number	C(Max)	Si (Max)	Mn(Max)	P(Max)	S(Max)	Al_{total} min[b]
E155	1.0033	0.11	0.35	0.70	0.025	0.025	0.015
E190	1.0031	0.10					
E195	1.0034	0.15	0.35	0.70	0.025	0.025	0.015
E220	1.0215	0.14					
E235	1.0308	0.17	0.35	1.20	0.025	0.025	0.015
E260	1.0220	0.16					
E275	1.0225	0.21	0.35	1.40	0.025	0.025	0.015
E320	1.0237	0.20					
E355	1.0580	0.22	0.55	1.60	0.025	0.025	0.020
E370	1.0261	0.21					
E420	1.0575	0.16	0.50	1.70	0.025	0.025	0.020

[a] **Elements** not included in this table (but see footnote°°) shall not be intentionally added to the steel without the agreement of the purchaser, except for the elements which may be added for the purposes of the deoxidation and/or nitrogen binding. All appropriate measures shall be taken to prevent the addition of the undesirable elements from the scrap or other materials used in the steel making process.

[b] This requirement is not applicable provided the steel contains a sufficient amount of other nitrogen binding elements such as Ti ,Nb, or V. When using titanium, the manufacturer shall verify that (Al+Ti/2)>0.020. Additions of the Nb,Ti and V are permitted at the description of the manufacturer. The content of these elements shall be reported.

Table 2 – Table 2 of EN 10305-3

The following table specifies the permissible deviations of the product analysis from the specified limits on cast analysis given in the above table.

Element	Limiting values for the cast analysis in accordance with table 2 %by mass	Permissible deviation of the product analysis % by mass
C	<0.22	+0.02
Si	<0.55	+0.05
Mn	<1.70	+0.10
P	<0.025	+0.005
S	<0.025	+0.005
Al	>0.015	-0.005

Table 3 – Table 3 of EN 10305-3

Differences between S2 and S3

As we saw previously seen into description of standard EN 10305, standard itself allows production with different kind of material, even though steel grade name is the same for the different surface condition; those differences are given with different kind of process used for the production of the coils.

S1 tubes are mainly used for construction application and are characterized with high thickness (>4mm) and a surface not useful neither for painting because of rust residual and no good visual aspect.

To produce S2 tubes, coils need to be processed with pickling operation; in this process the coil is washed with acids specially with HCl and get heated with temperature range of 80 to 90° degrees in order to clean the surface from oxides and scaling and give better look to the coil.

With pickled material is possible to reach minimum 1.5mm of thickness and a surface suitable for painting application or galvanizing with an average roughness of 1 to 2 µm.

After that, S3 material is needed to reach lower thickness (till 0.5mm) and to guarantee a roughness of the material that is suitable also for the chroming application, with an average roughness of 0.2 to 0.4 µm.

This process including annealing process plus Skinpass steps to treat the coil for desire properties in a gentle way. We give here heat treatment ranging from 600-700° degrees and then cool down the coil gradually for better performances and customer demands.

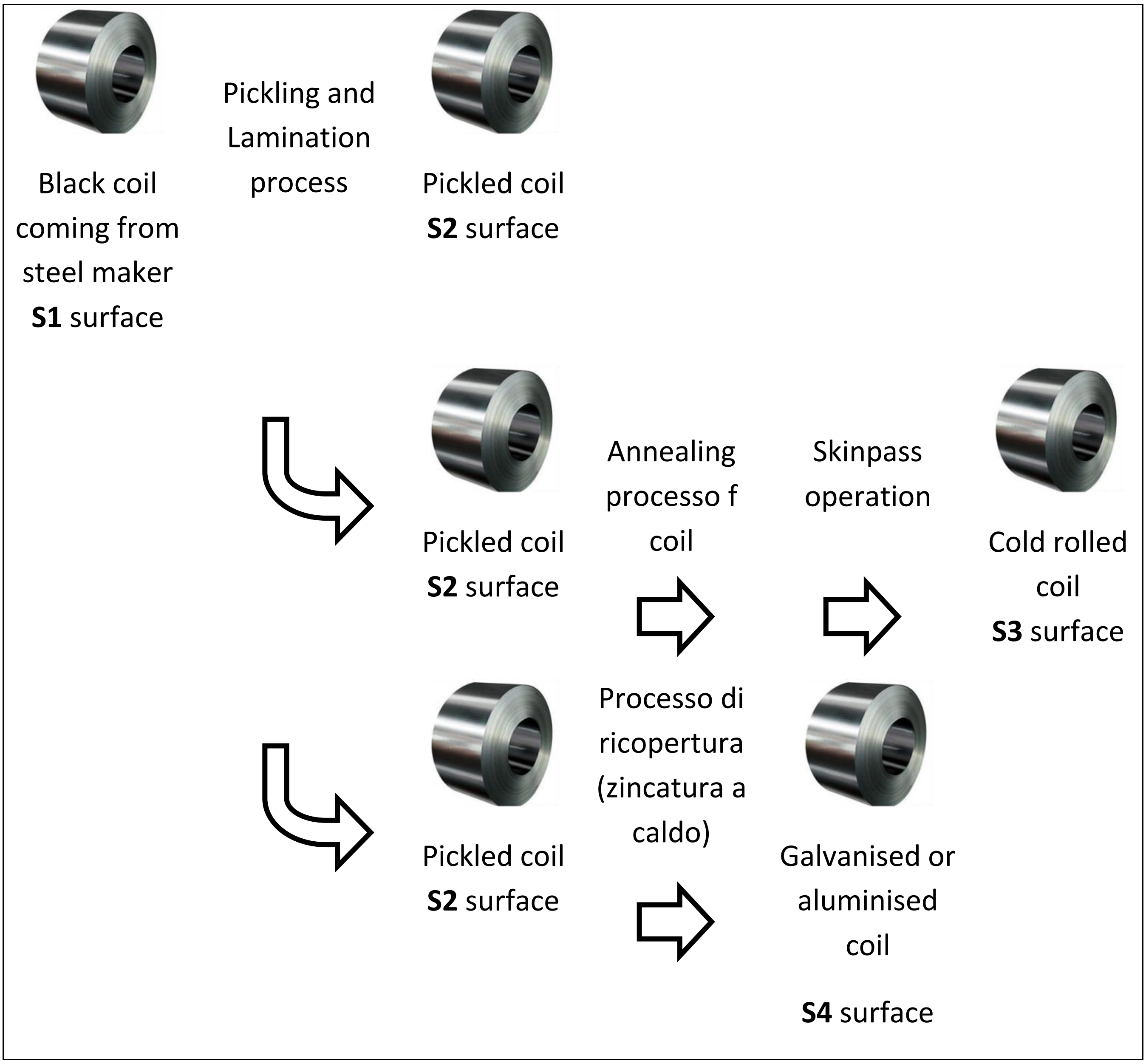


Table 4 – production flow process for coils

2. Different pairs of materials

During this thesis we will start from three different kind of steelgrade commonly produced in Marcegaglia plant and we will compare product certified as same grade of material but obtained from different raw material process (S2 and S3).

Steelgrade	Raw material	Tube quality description
Pickled raw material (S2)	Sae1006	E220+CR2**S2**
Cold rolled raw material (S3)	DC01	E220+CR2**S3**
Pickled raw material (S2)	S235	E235+CR1**S2**
Cold rolled raw material (S3)	FE360	E235+CR1**S3**
Pickled raw material (S2)	S355MC	E370+CR2**S2**
Cold rolled raw material (S3)	HC380LA	E370+CR2**S3**

Chemical comparison

Because of the starting raw material is the same, S2 and correspondent S3 material will always have same base chemical composition.

In the following graphs it can be seen the composition of the four elements **Si ,C ,P ,S** are the same for both the above mentioned couple materials. Which also verify the above mentioned value in the table 1.

Reported analysis shows we will see that no trend are present even with testing different pair of raw material, in fact production process shown in Table 4 do not modify chemical composition of material.

E220 tube (raw material Sae1006 & DC01)

Tubes produced with this raw material has name E220, characteristic of this product is to have good bending properties and suitable for many application, chemical compositions of raw material is shown in the graphs.

Main percentage of chemical component is Carbon that is also the most influent for the mechanical behavior.

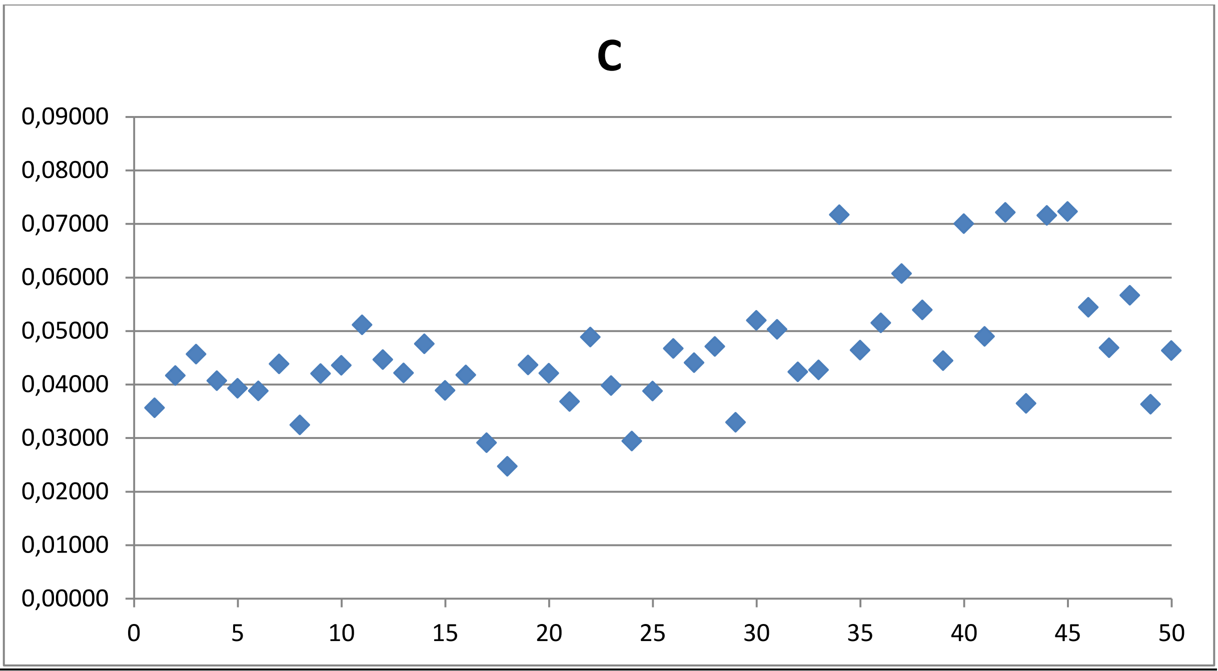


Figure 1– carbon content for SAE1006 based material

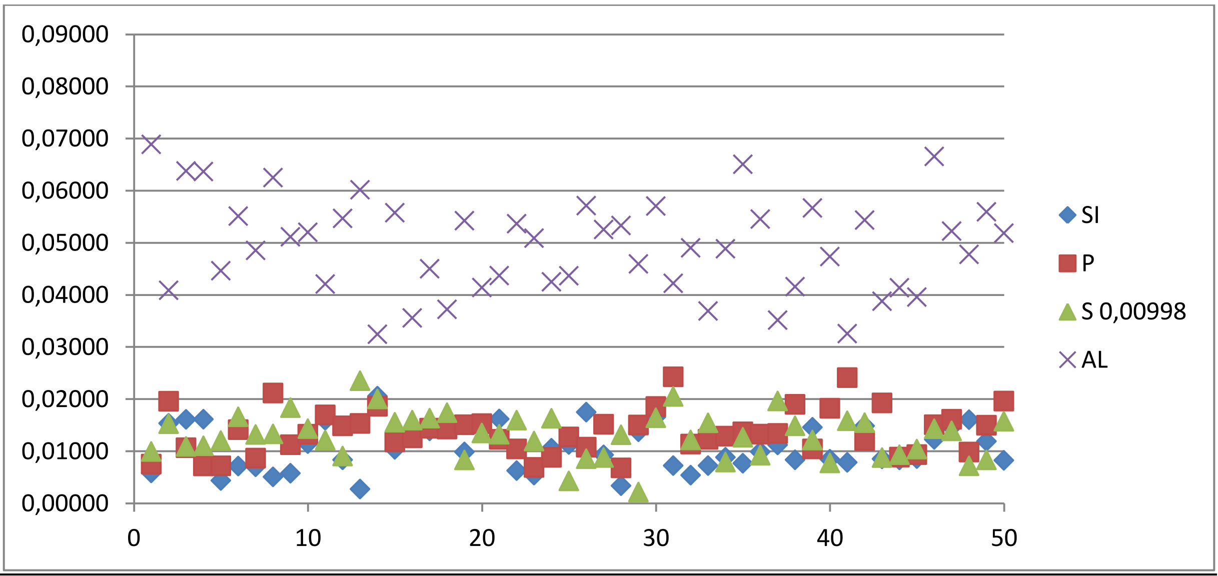


Figure 2 – other elements for SAE1006 based material

All the chemical analysis performed on this range of material is reported below:

	C	Si	Mn	P	S	Al
Max EN	0.14	0.35	0.70	0.025	0.025	-
Max	0.075	0.020		0.024	0.0235	0.070
Min	0.024	0.002		0.006	0.0022	0.030
Min EN	-	-	-	-	-	0.015

Table 5 – main chemical elements of tube E220

E235 tube (raw material S235 & FE360)

Tubes produced with this raw material has name E235, characteristic of this product is to have good bending properties with higher tensile strength resistance; main difference of this material is an higher percentage of Carbon that allows those tube to be commonly used also for annealing process (+N), this process allows to improve more the bending characteristics of the product.

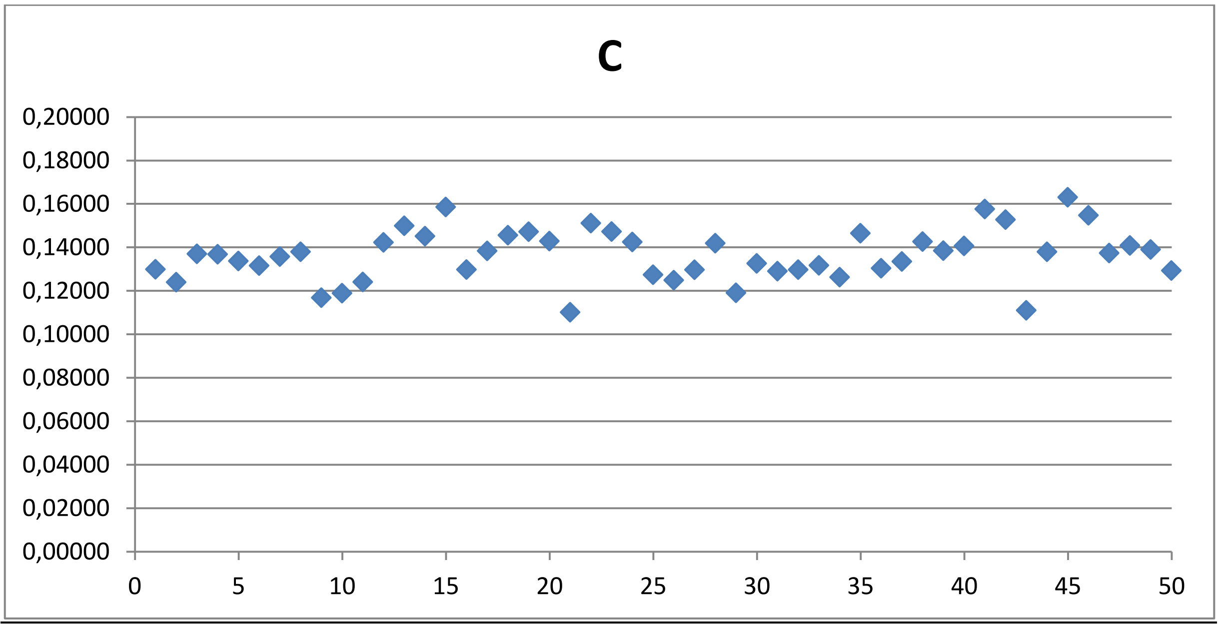


Figure 3– carbon content for S235 based material

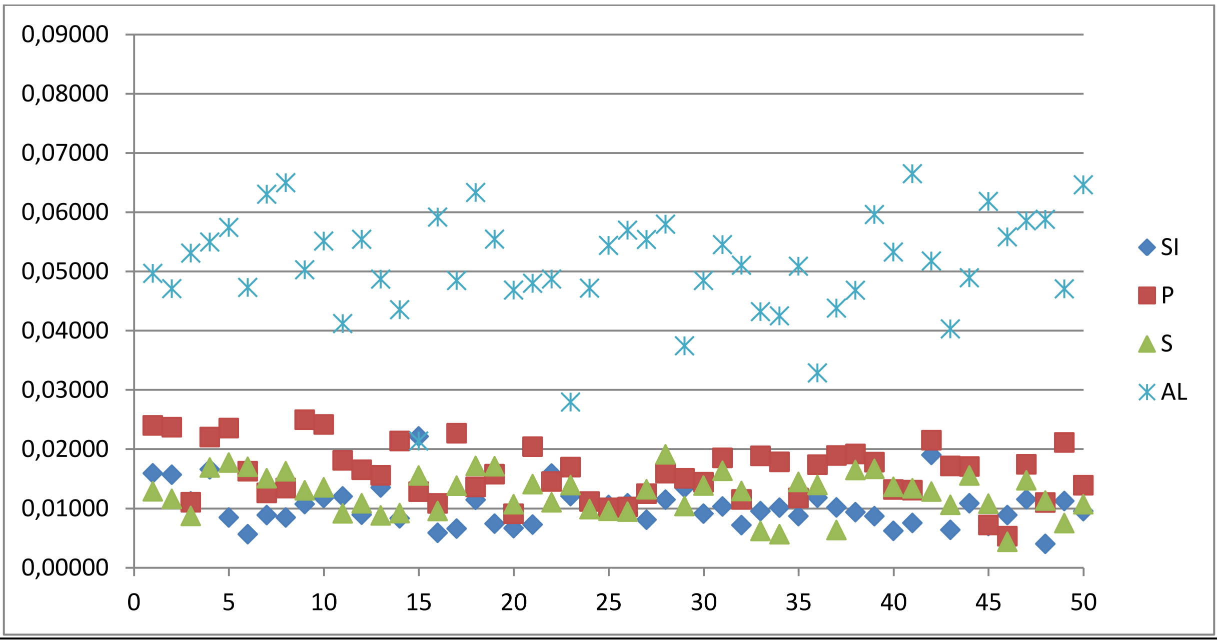


Figure 4 – other elements for S235 based material

All the chemical analysis performed on this range of material are reported below:

	C	Si	Mn	P	S	Al
Max EN	0.14	0.35	0.70	0.025	0.025	0.07
Max	0.136	0.022	0.60	0.025	0.019	0.066
Min	0.110	0.004	0.40	0.005	0.004	0.04
Min EN	-	-	-	-	-	0.015

Table 6 – main chemical elements of tube E235

E370 tube (raw material S355MC & HC380LA)

Tubes produced with this raw material has name E370, characteristic of this product is to still have a good bending capability with a higher tensile strength, this possibility is thank to insertion of Niobium and Vanadium; this micro-alloyed material, even with low %, are able to give higher performance to the material.

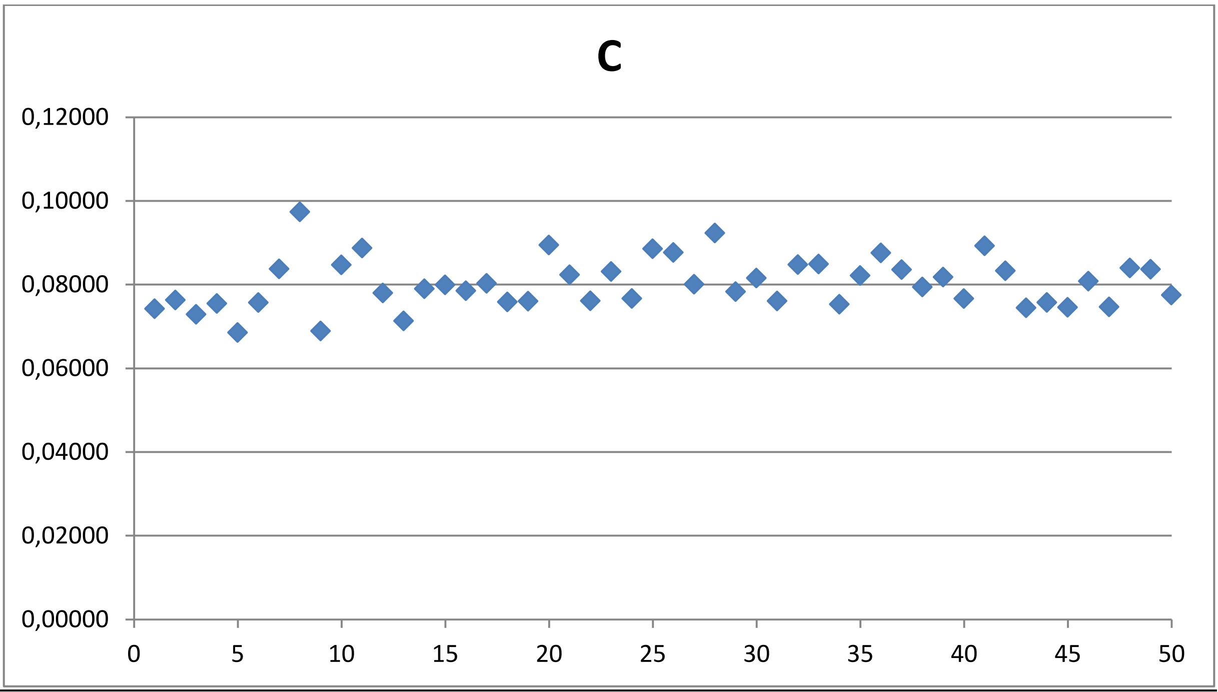


Figure 5 – carbon content for S355MC based material

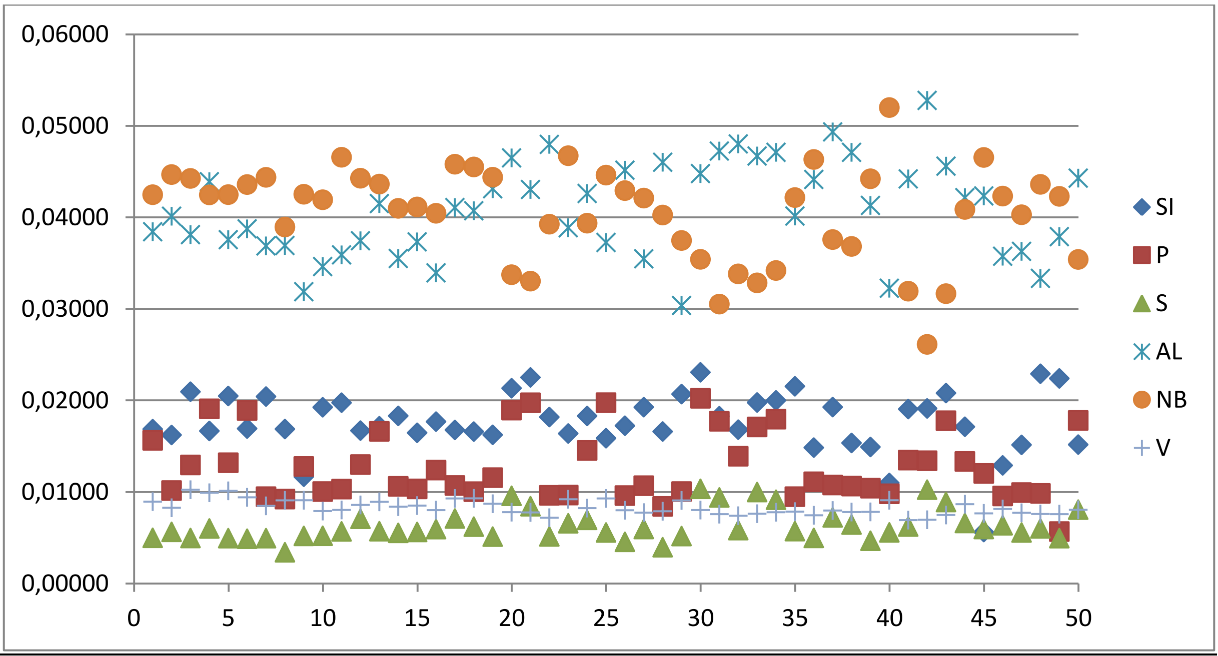


Figure 6 – other elements for S355MC based material

All the chemical analysis performed on this range of material are reported below:

	C	Si	Mn	P	S	Al	Nb	Va
Max EN	0.14	0.35	0.70	0.025	0.025		-	-
Max	0.100	0.022	0.76	0.020	0.003	0.08	0.058	0.01
Min	0.075	0.010	0.60	0.005	0.010	0.02	0.023	0.006
Min EN	-	-	-	-	-	0.015	-	-

Table 7 – main chemical elements of tube E370

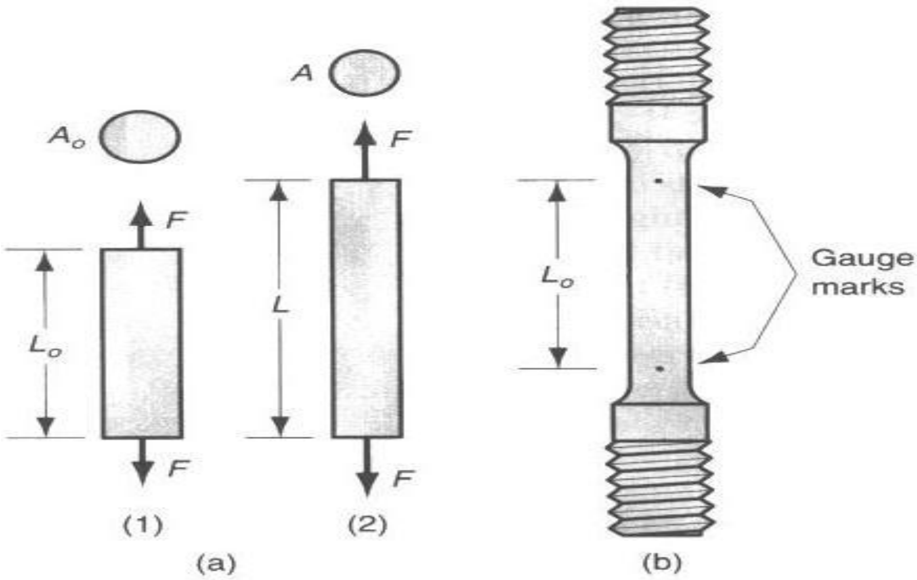
3. Mechanical analysis of the Materials:

Introduction:

Mechanical properties that are important to a design engineer differ from those that are of interest to the manufacturing engineer.

- In design, mechanical properties such as elastic modulus and yield strength are important in order to resist permanent deformation under applied stresses. Thus, the focus is on the elastic properties.
- In manufacturing, the goal is to apply stresses that exceed the yield strength of the material so as to deform it to the required shape. Thus, the focus is on the plastic properties.
- The yield behavior of a material is determined from the stress-strain relationship under an applied state of stress (tensile, compressive or shear).
- This lab introduces the uniaxial tensile test to determine the basic mechanical properties of a material. The main focus of this lab is on the plastic properties of the material.

Tensile Test- Basic Principles:

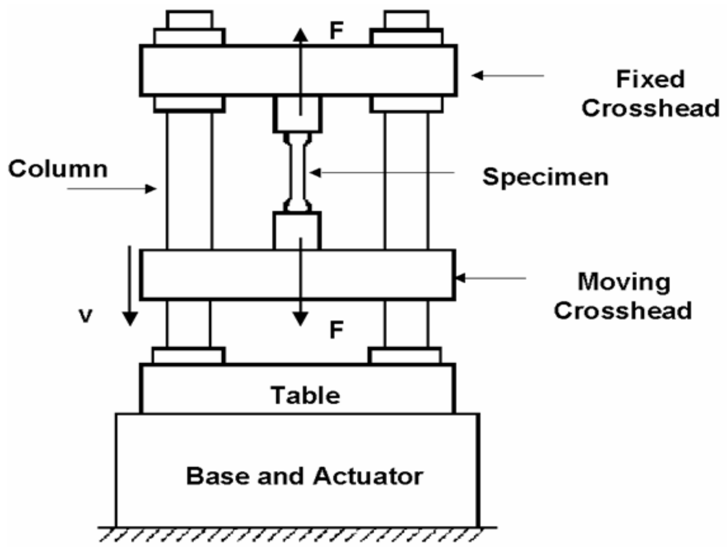


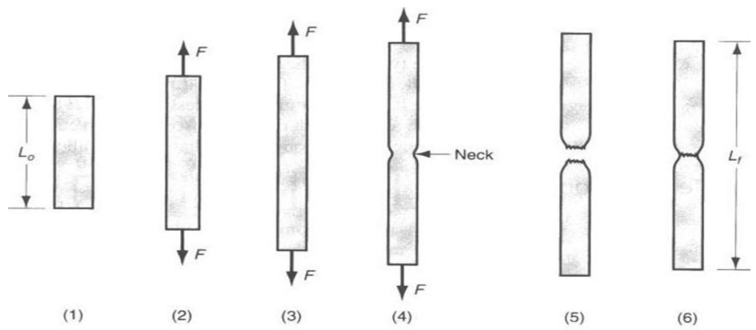
- An axial force applied to a specimen of original length (lo) elongates it, resulting in a reduction in the cross-sectional area from Ao to A until fracture occurs.
- The load and change in length between two fixed points (gauge length) is recorded and used to determine the stress-strain relationship.
- A similar procedure can be adopted with a sheet specimen.

Basic Principles:

- Step 1: Original shape and size of the specimen with no load.

- Step 2: Specimen undergoing uniform elongation.
- Step 3: Point of maximum load and ultimate tensile strength.
- Step 4: The onset of necking (plastic instability).
- Step 5: Specimen fractures.
- Step 6: Final length.



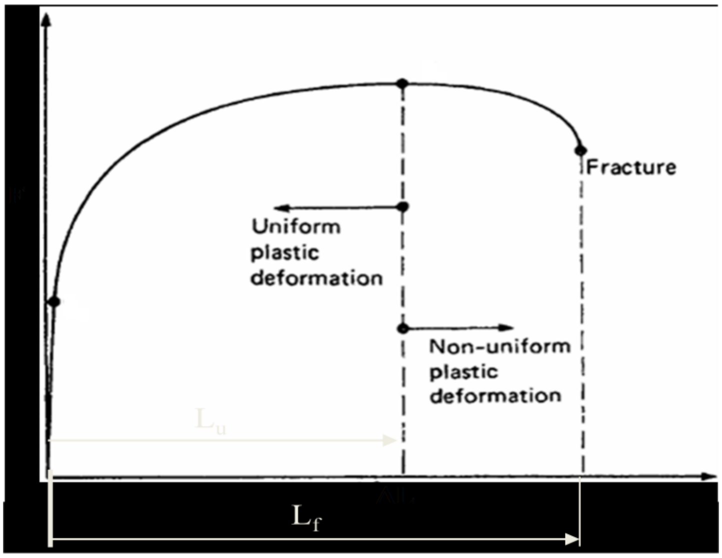


<u>Primary Test Output</u>:

The primary output from a tensile test is the load vs. elongation curve of the specimen, which is recorded in real-time using a load cell and an extensometer. This curve is then used to determine two types of stress-strain curves:

- Engineering stress-strain.

– True stress-strain.



Terminology:

– Engineering Stress and Strain:

– These quantities are defined relative to the original area and length of the specimen.

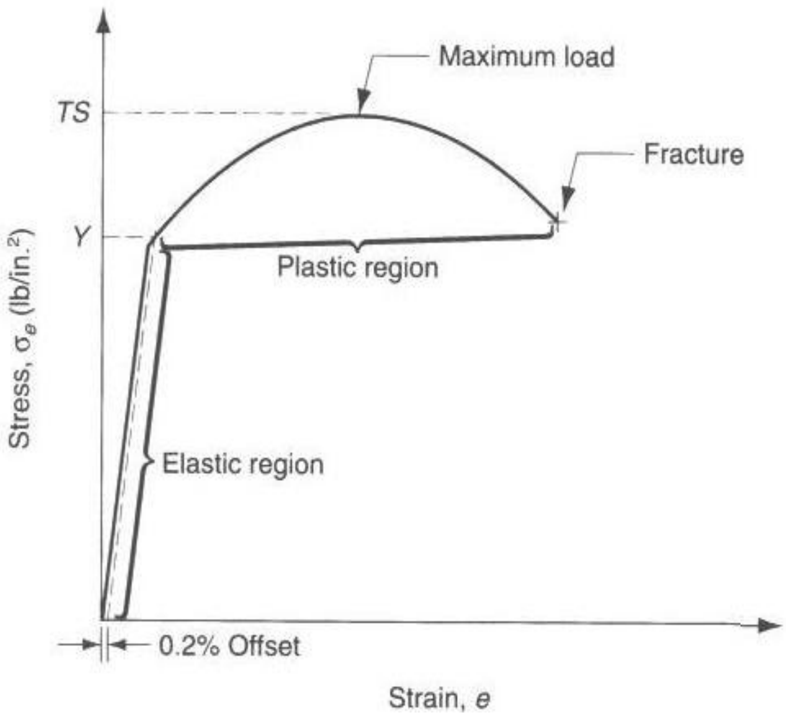
– The engineering stress (σe) at any point is defined as the ratio of the instantaneous load or force (F) and the original area (Ao).

– The engineering strain (e) is defined as the ratio of the change in length (L-Lo) and the original length (L_o).

$$\sigma_e = \frac{F}{A_o} \quad e = \frac{L - L_o}{L_o}$$

- The engineering stress-strain curve (σ_e- e) is obtained from the load-elongation curve.
- The yield point, called the yield strength (Y), signifies the start of the plastic region.

Engineering Stress Vs Strain Curve

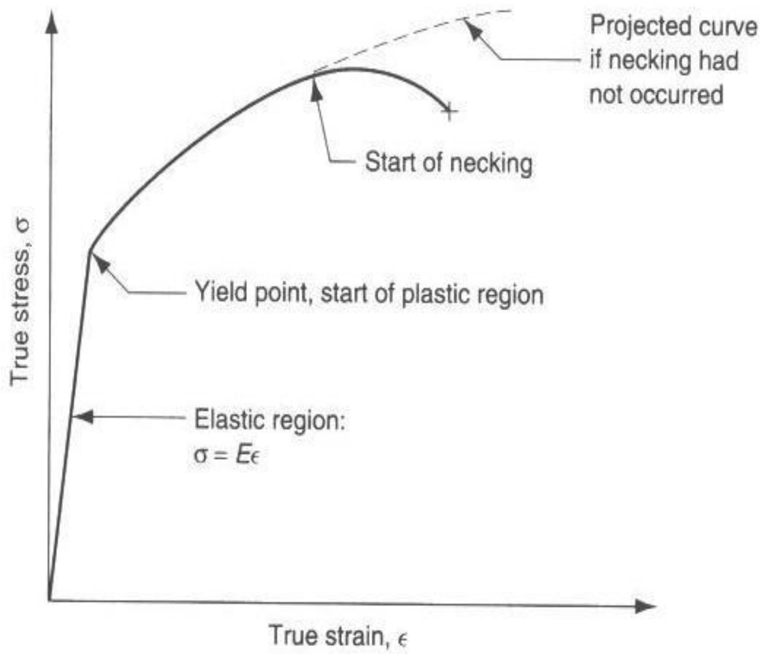


Ductility:

- Ductility can be defined as the amount of deformation or strain that the material can withstand before failure. For metal forming processes, increasing the ductility increases the material formability.
- In general, the ductility of the specimen is defined in terms of the elongation (EL) or the area reduction (AR) before fracture, i.e.:

$$AR = \frac{A_o - A_f}{A_o} \qquad EL = \frac{L_f - L_o}{L_o}$$

True Stress Vs Strain Curve



Note: For a given value of the load and elongation, the true stress is higher than the Eng. Stress, while the true strain is smaller than the Eng. Strain.

Procedure of performing the test:

The procedure and the specimens for tensile tests must comply with the requirement of EN 6892-1 Testing Part 1: Method of test at ambient temperature.

For mechanical analysis we go back to see the original casting properties of the testing tube present in our network systems. The length of these specimens is 320 mm.

According to the section of production concerned, there are two methods of the preparation of the specimens.

---One is for diameter > 50mm.

---One is for diameter <50mm.

In the first case we cut the tube with cutting tools and we get 22mm strips from the tube and then we go for the mechanical tensile test.

In the second case we do not need to cut the tube, we get information about the tube from the computer data and we put the important data into the mechanical test machine software in the system after verification of the diameter and thickness of the specimen with the official tools like Screw gauge and Vernier caliper, then we inserted solid rods of steel of both side of the specimen before inserting into the test machine as shown in the picture below.

Figure 7 – tensile test machine

The above part is mobile which apply upward force on the specimen and the below part is stationary and do not move.

The specimen should be inserted carefully into the terminals of the above part and below part in order to break the specimen at the middle for better mechanical results.

The final results include the following important terms of the data.

---Yield strength (Rp02).

--- Tensile strength (Rm).

---Elongation (A_5%).

The important data graphs during the test are the following ones which show how they are related to the above mentioned terms.

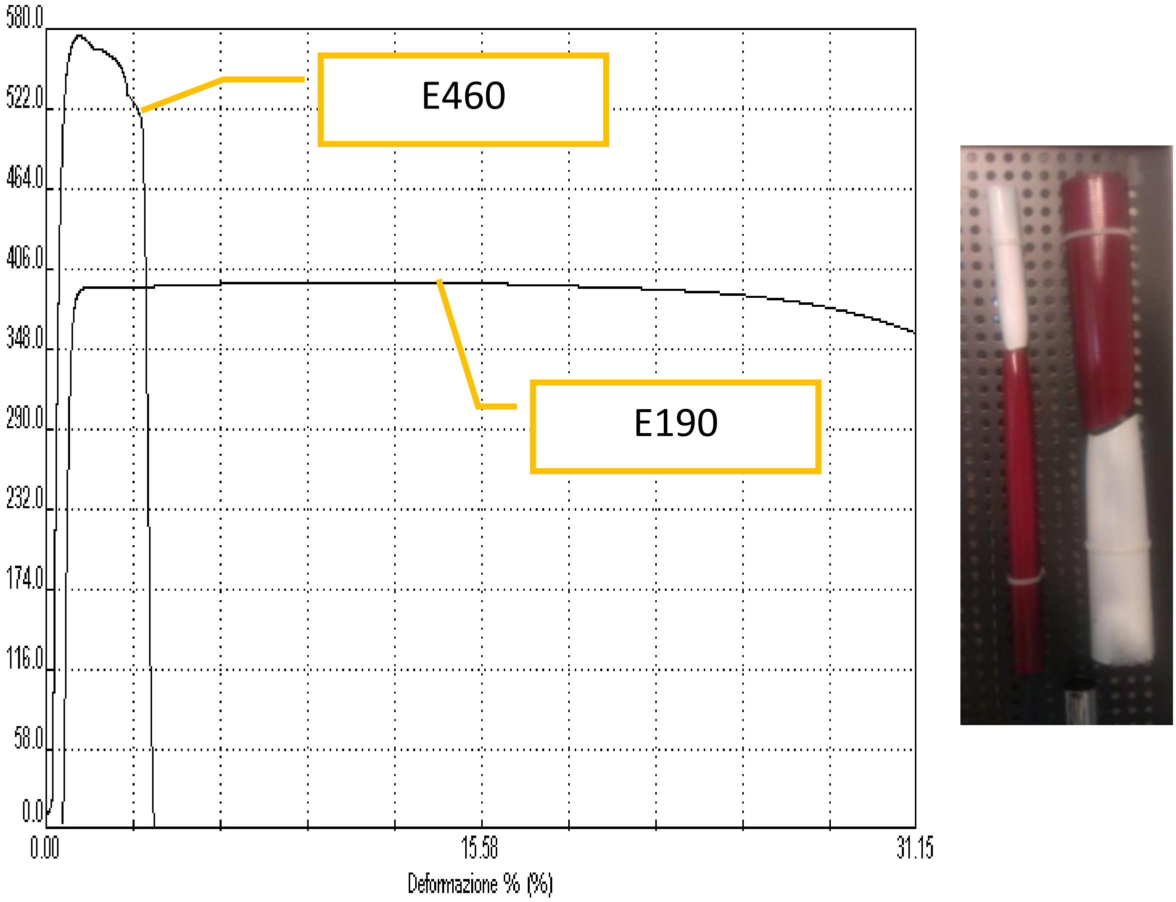


Figure 8 – difference of results between "hard" and "soft" material

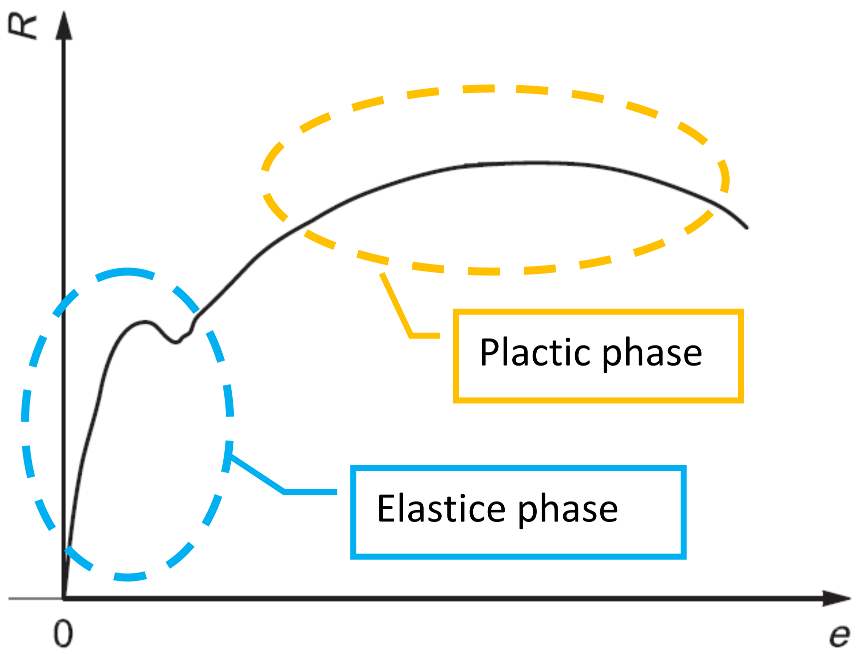


Figure 9 – identification of different phases during tensile test

This lab preparation material introduced:

- The basic principles of the tensile test and the terminology used (stress, strain, ductility, strain hardening)
- The objectives of and the expected outcomes from the evaluation of test results.
- The testing equipment and the test procedure, and
- The effect of strain hardening and ductility upon deformation in the tensile test through simulations.

Mechanical comparison

E220 tube (Sae1006 vs DC01)

Following it will be reported measurement get from mechanical tests performed into laboratory, as we previously see chemical elements for both material (in this case strip SAE1006 and DC01) are exactly the same, even so mechanical results are different.

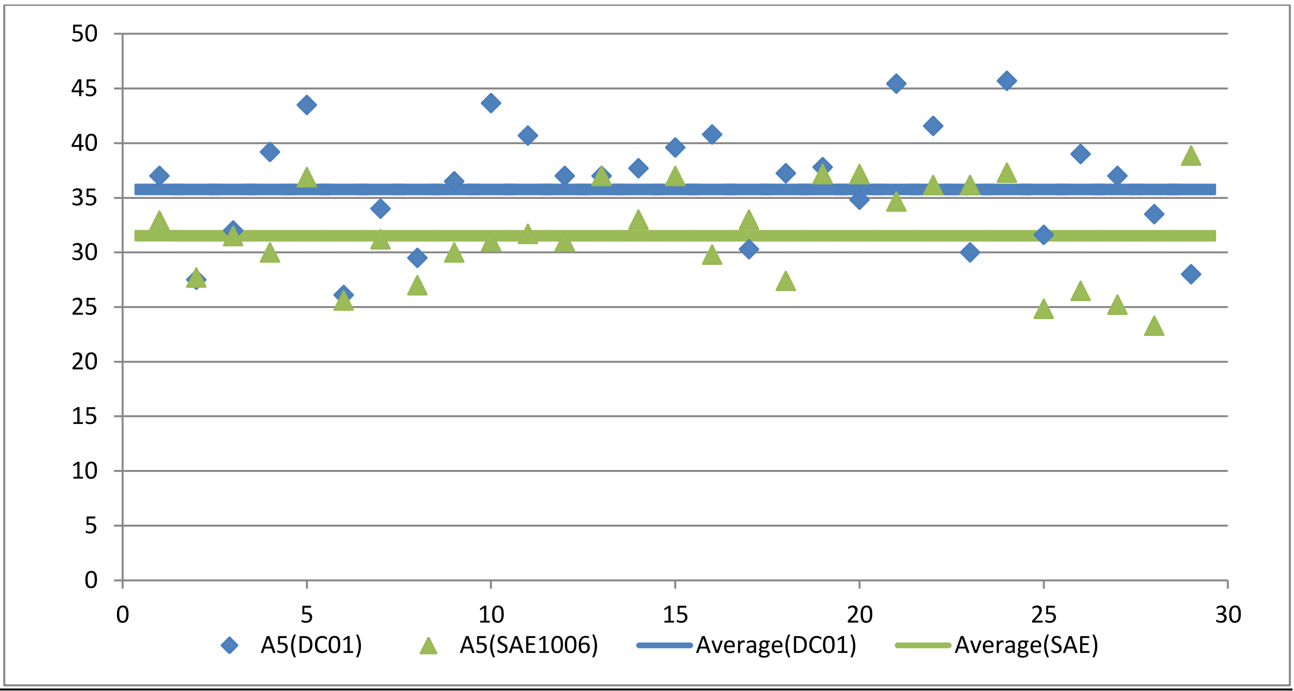


Figure 10 – elongation comparison sae1006 vs DC01

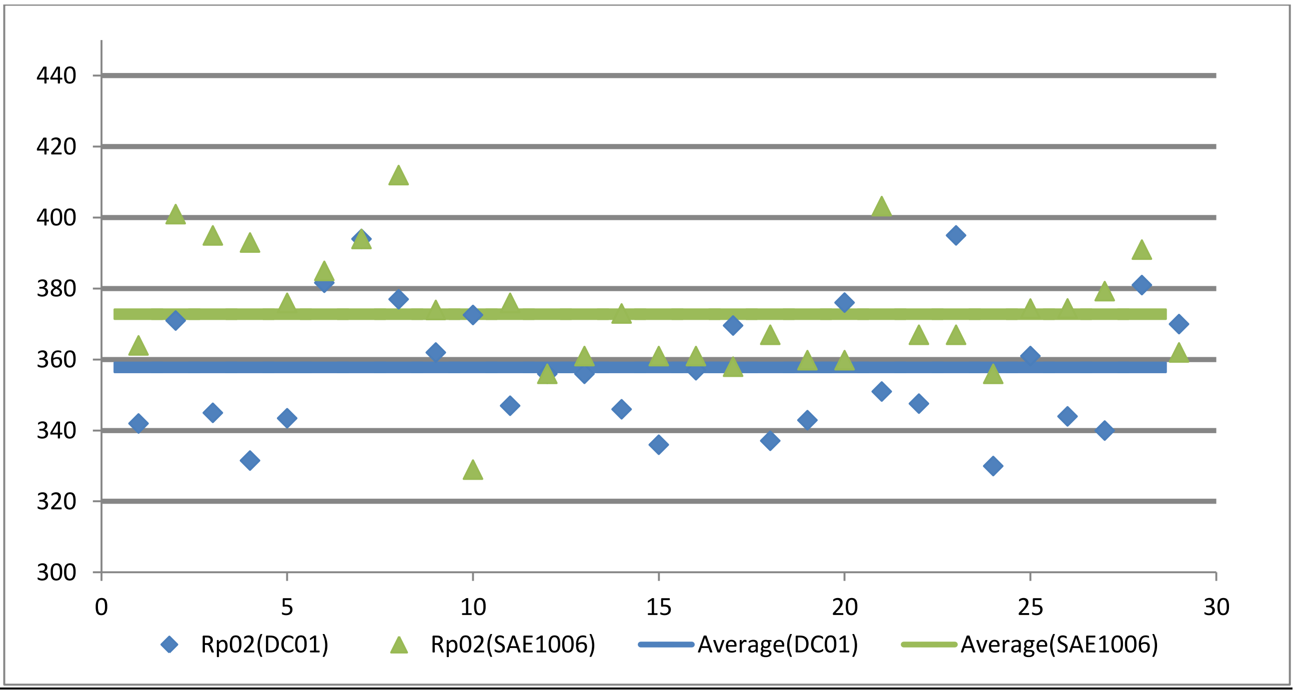


Figure 11 – yeld strenght comparison sae1006 vs DC01

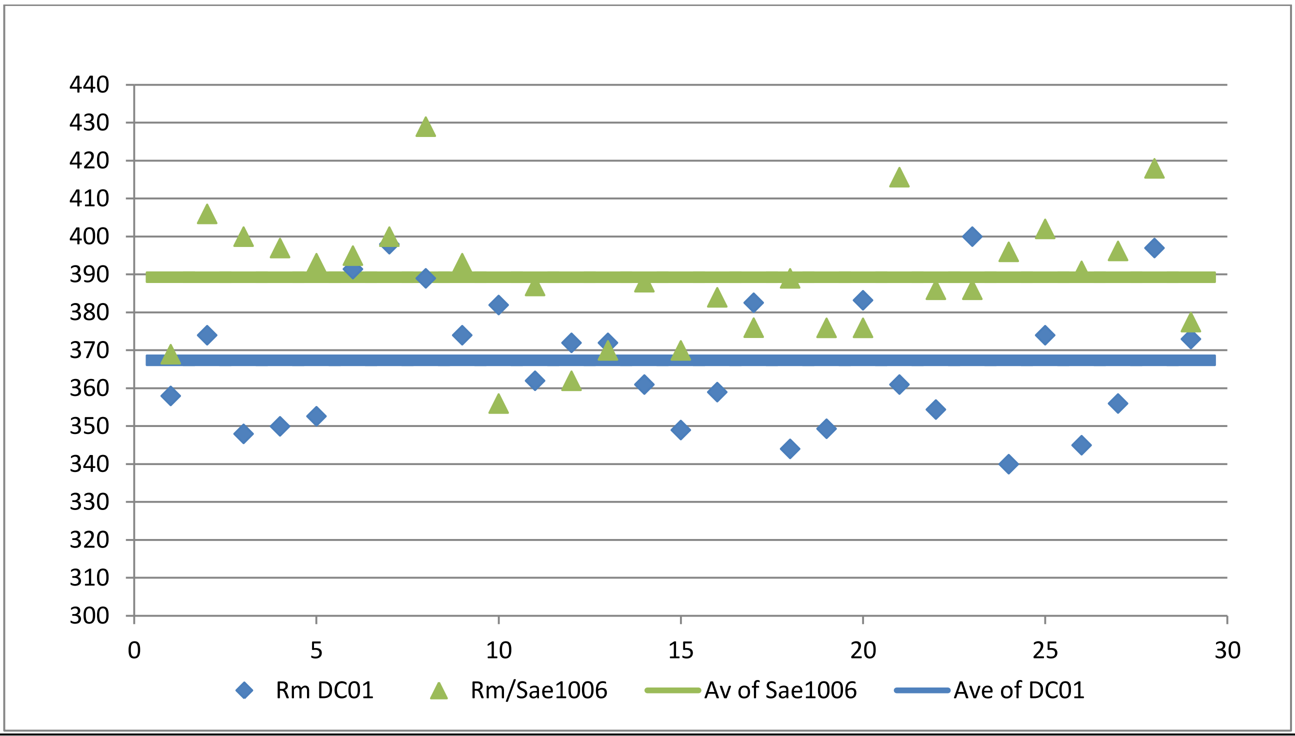


Figure 12– tensile strenght comparison sae1006 vs DC01

Looking at measurement it can be seen that S3 material (DC01) has better bending capability with an average higher elongation and lower resistance.

Properties	Sae1006	DC01
Rm	389	367
Rp02	372	357
A5%	31.52	**35.76**

E235 tube (S235 vs FE360)

Following it will be reported measurement get from mechanical tests performed into laboratory, as we previously see chemical elements for both material are exactly the same, even so mechanical results are different.

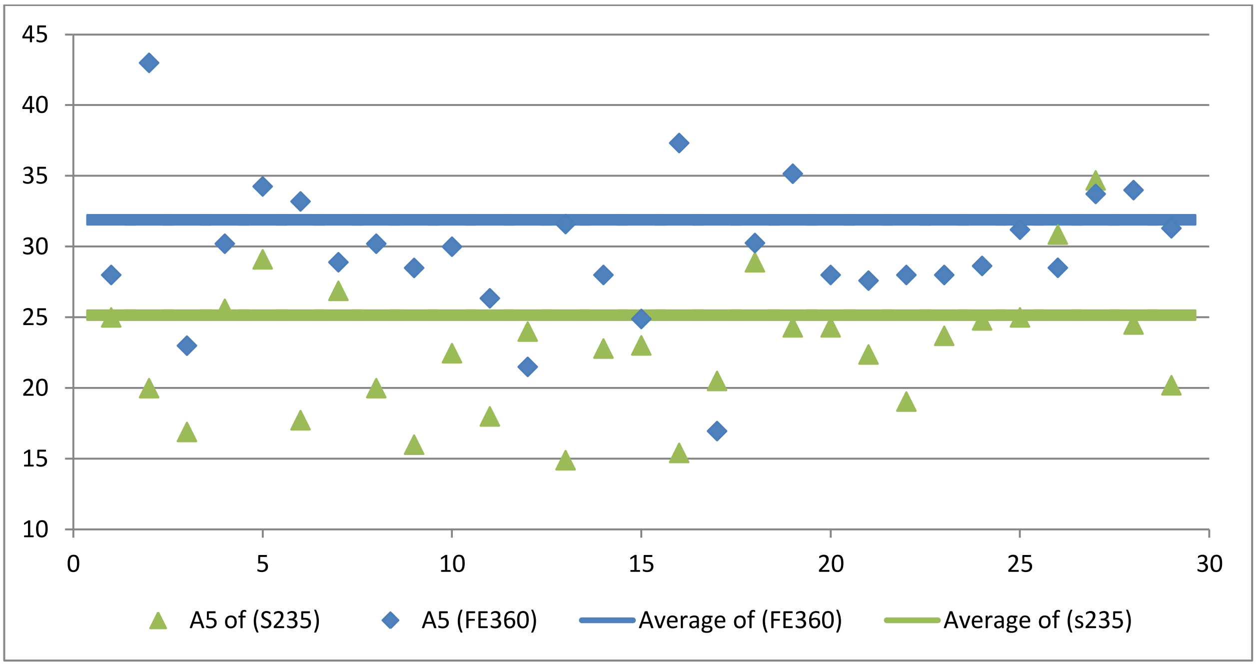


Figure 13 – elongation comparison S235 vs FE360

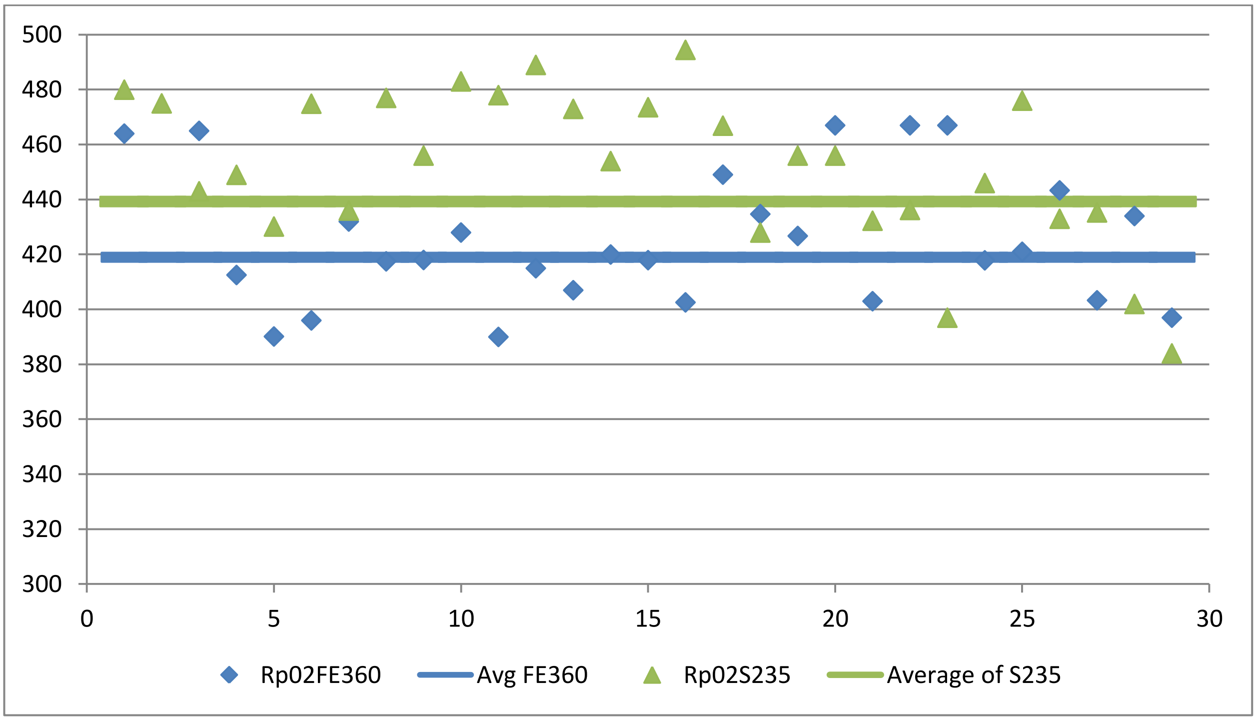


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Figure 14– yeld strenght comparison S235 vs FE360

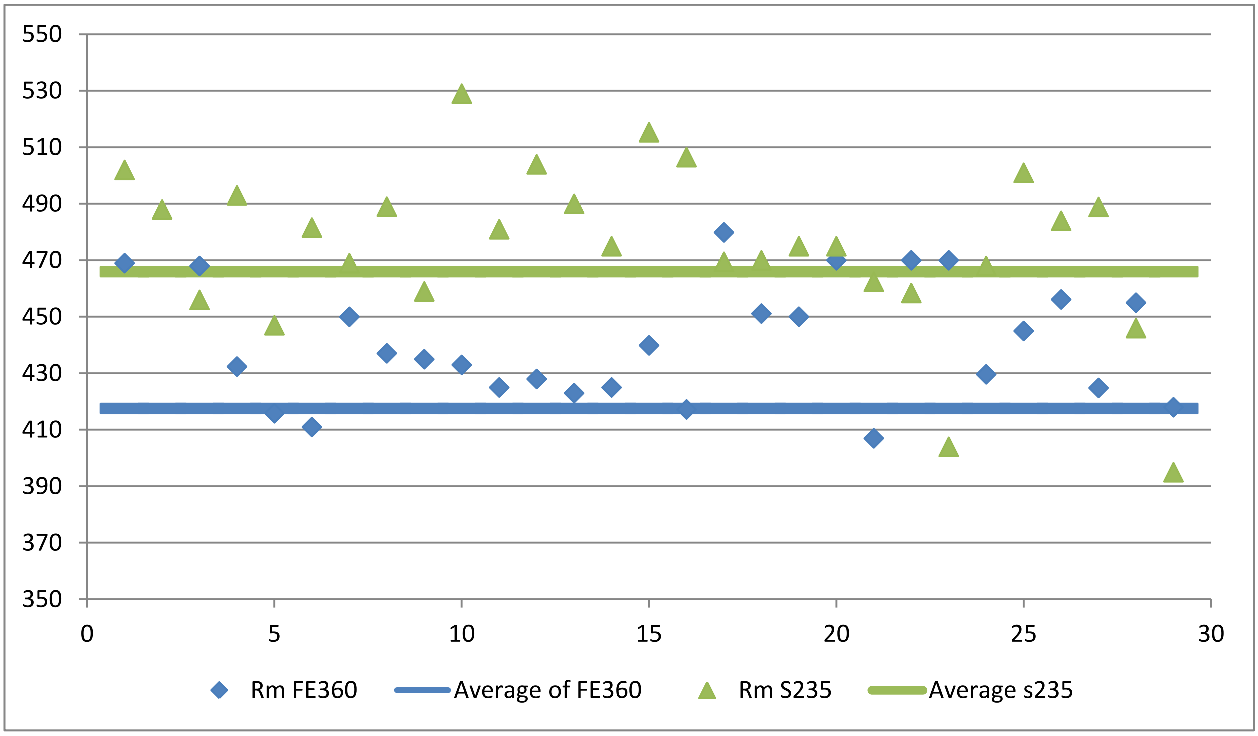

Figure 15– tensile strenght comparison S235 vs FE360

Same results has been get with these two pairs of materail where S3 material has better elongation and consequently better bending capability.

Properties of tube	S235	FE360
Rm	466	418
Rp02	439	419
A5%	25	31.9

E370 tube (S355MC vs HC380LA)

Following it will be reported measurement get from mechanical tests performed into laboratory, as we previously see chemical elements for both material are exactly the same, even so mechanical results are different.

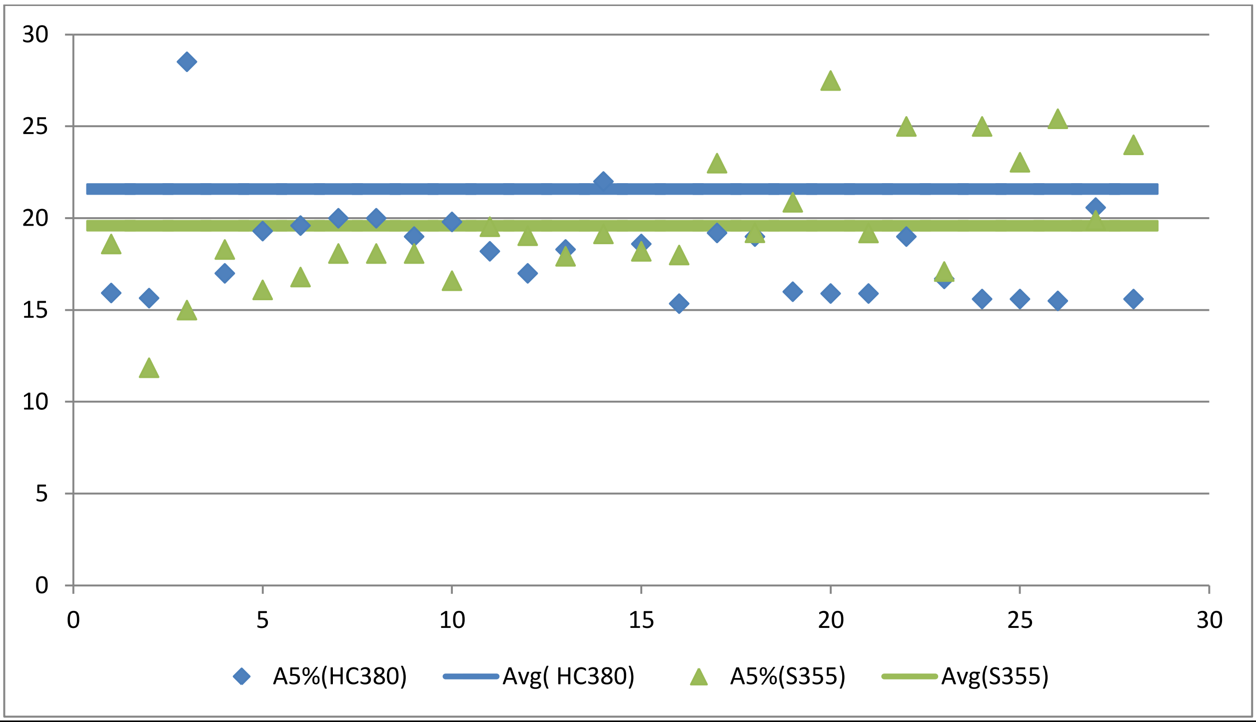

Figure 16– elongation comparison S355MC vs HC380

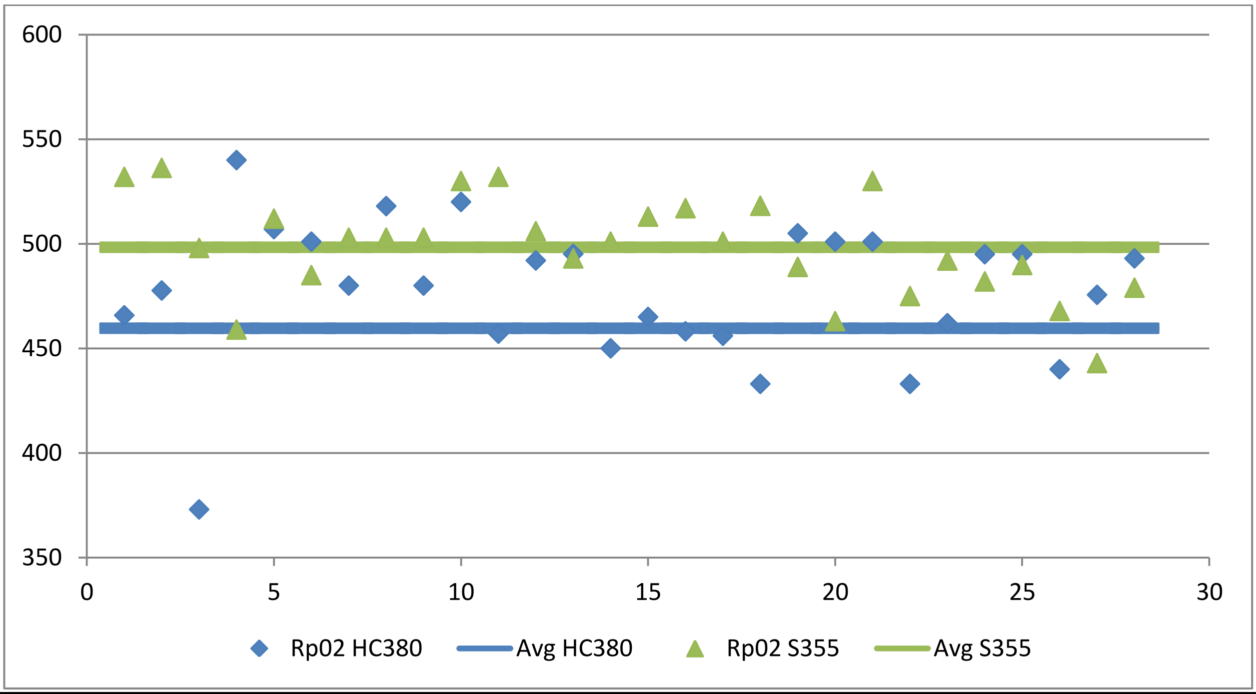

Figure 17– yeld strenght comparison S355MC vs HC380

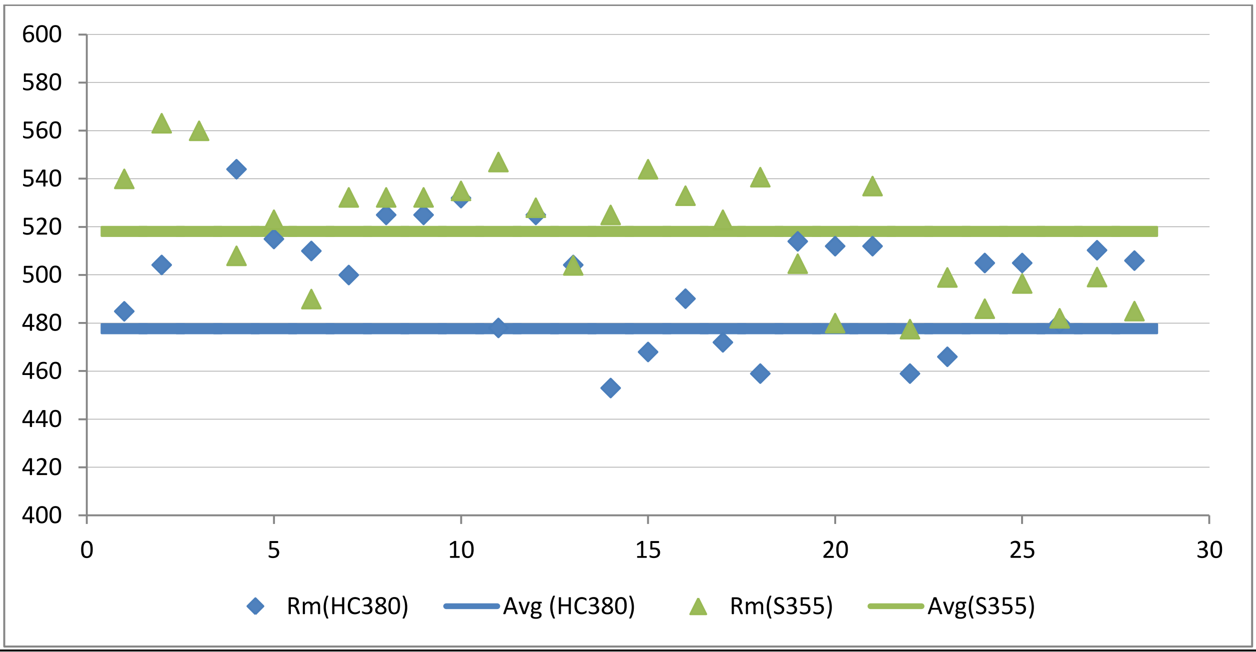

Figure 18– tensile strenght comparison S355MC vs HC380

Same results has been get with these two pairs of material where S3 material has better elongation and consequently better bending capability.

Properties of tube	S355MC	HC380LA
Rm	518	478
Rp02	498	460
A5%	19.6	21.5

4. Microstructure analysis

With the different kind of materials it has been done several micrography at the material structure, the images are needed to understand link between mechanical results we got from tensile tests and the structure of the material.

Following we will report pictures of micrography from different kind of materials.

The grain size we will see into the following pictures will show tipical distribution of material with the different kind of material we analyzed; micrography has been made with pieces of strips material, we did not use pieces of tube in order to avoid plastic deformation due to bending process of tube production.

Pickled material should have a grain size with more inconstant dimension and, depending of percentage of thickness reduction, with visible longitudinal direction, this deformation of grain do not allows to reach higher elongation performance possible.

This deviation can be clearly seen in Figure 19 where SAE1006 grain size direction is clear, this deformation is completely disappeared with following annealing process for the production of correspondent S3 material (DC01) with same chemical analysis.

Microstructure is defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 25× magnification.[1] The microstructure of a material (which can be broadly classified into metallic, polymeric, ceramic and composite) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance, and so on, which in turn govern the application of these materials in industrial practice.

Microscopy

Optical

When a polished flat sample reveals traces of its microstructure, it is normal to capture the image using macro photography. More sophisticated microstructure examination involves higher powered instruments: optical microscopy, electron microscopy, X-ray diffraction and so on, some involving preparation of the material sample (cutting, microtome, polishing, etching, vapor-deposition etc.). The methods are known collectively as metallography as applied to metals and alloys, and can be used in modified form for any other material, such as ceramics, glasses, composites, and polymers.

Two kinds of optical microscope are generally used to examine flat, polished and etched specimens: a reflection microscope and an inverted microscope. Recording the image is achieved using a digital camera working through the eyepiece.

Electron microscopy

For high-resolution information on metallurgical microstructures, electron microscopic methods can be employed. This can allow for direct observation of atomic-scale features such as very fine precipitates, dislocations or grain-boundary interfaces. Such methods may be critical in determining parameters such as solid state diffusivities.

Sae1006 vs DC01

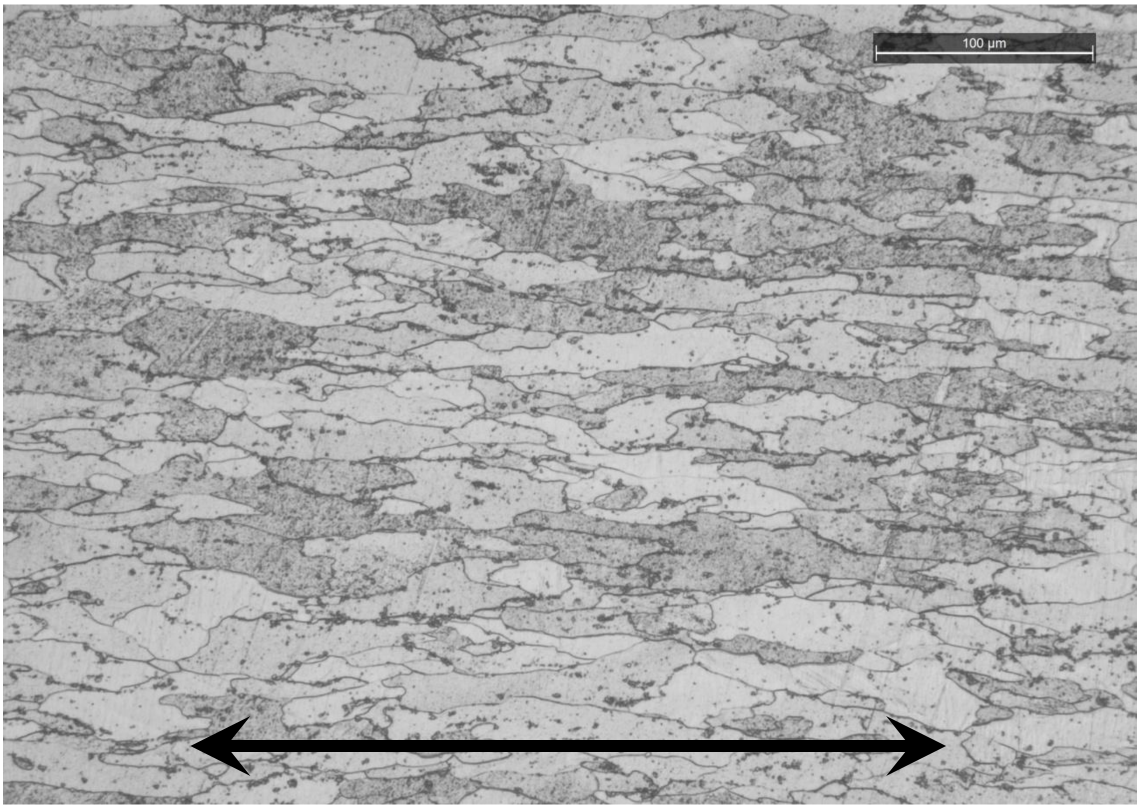

Figure 19– Sae1006 zoom 200X

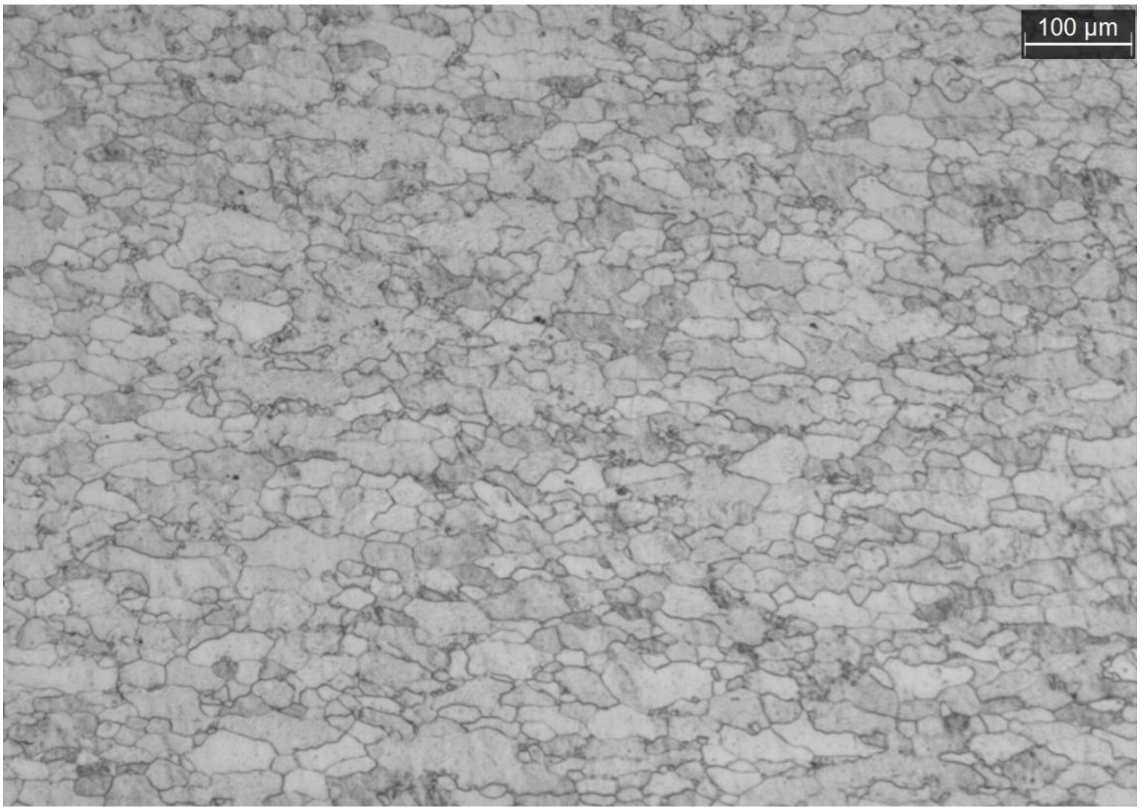

Figure 20 – DC01 zoom 200X

S235 vs FE360

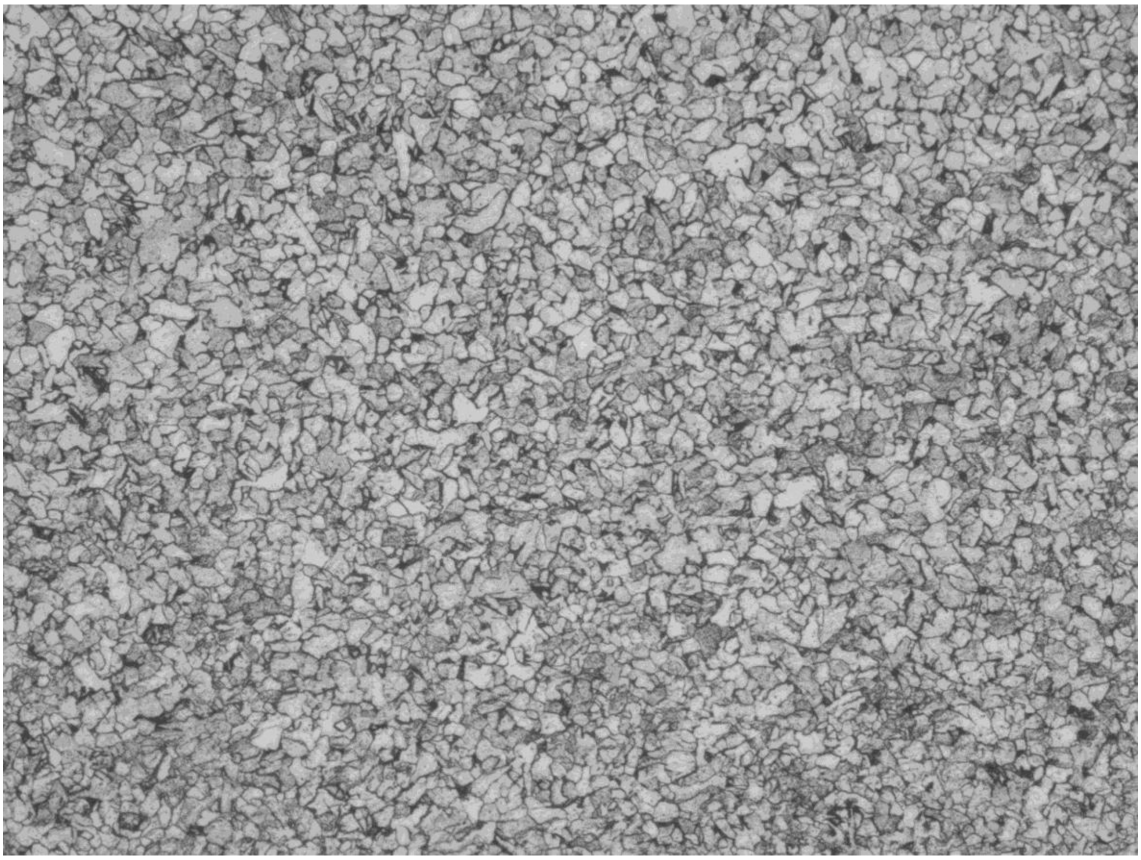

Figure 21 – S235 zoom 100X

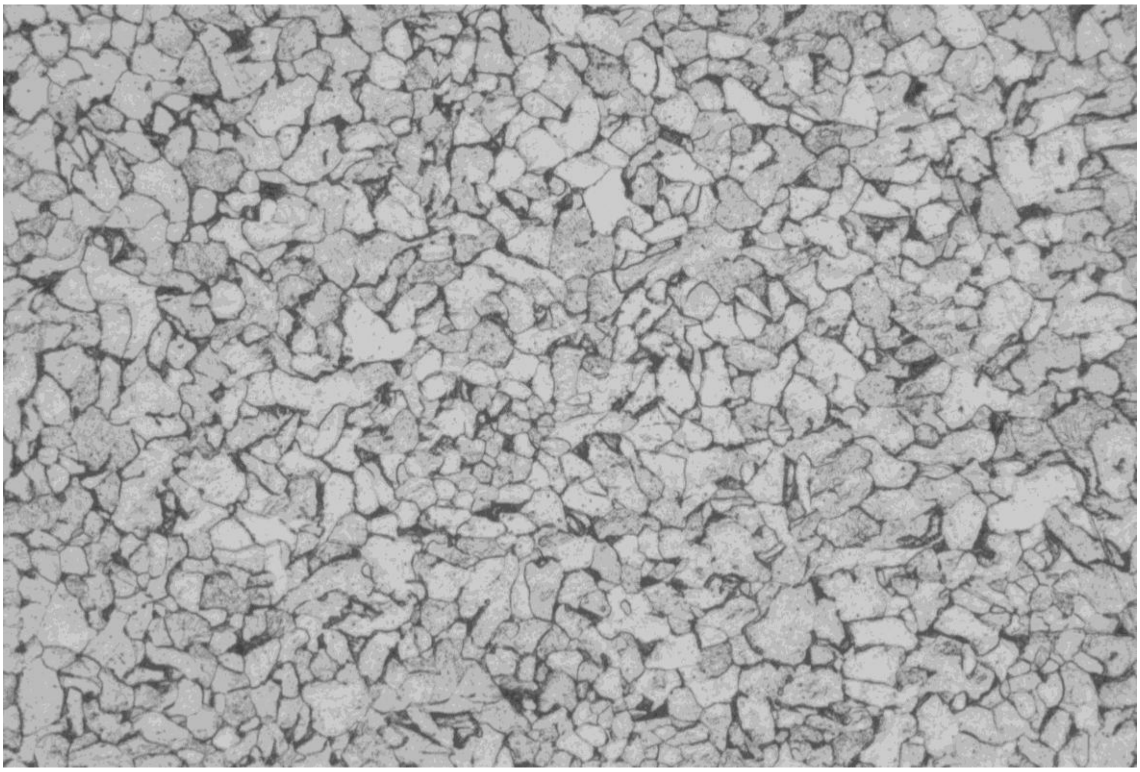

Figure 22 – S235 zoom 200X

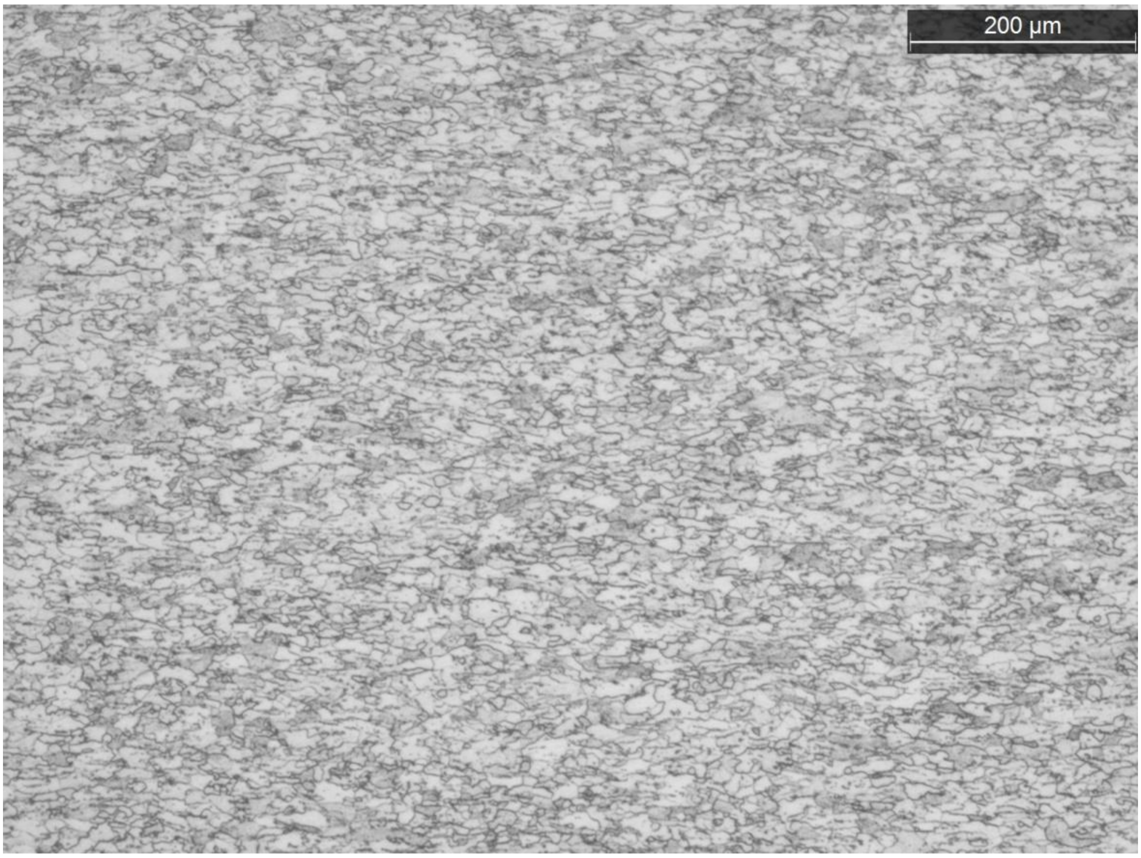

Figure 23 – FE360 zoom 100X

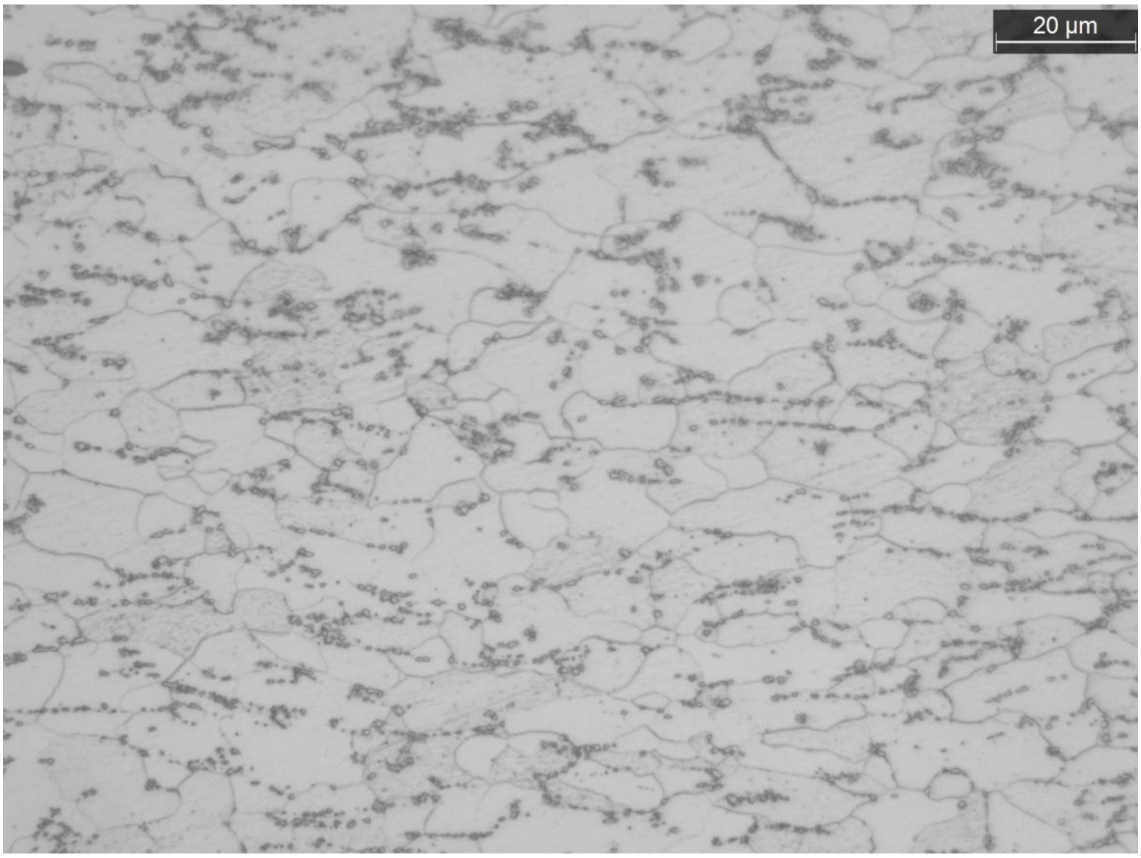

Figure 24 – FE360 zoom 500X****

S355MC vs HC380LA

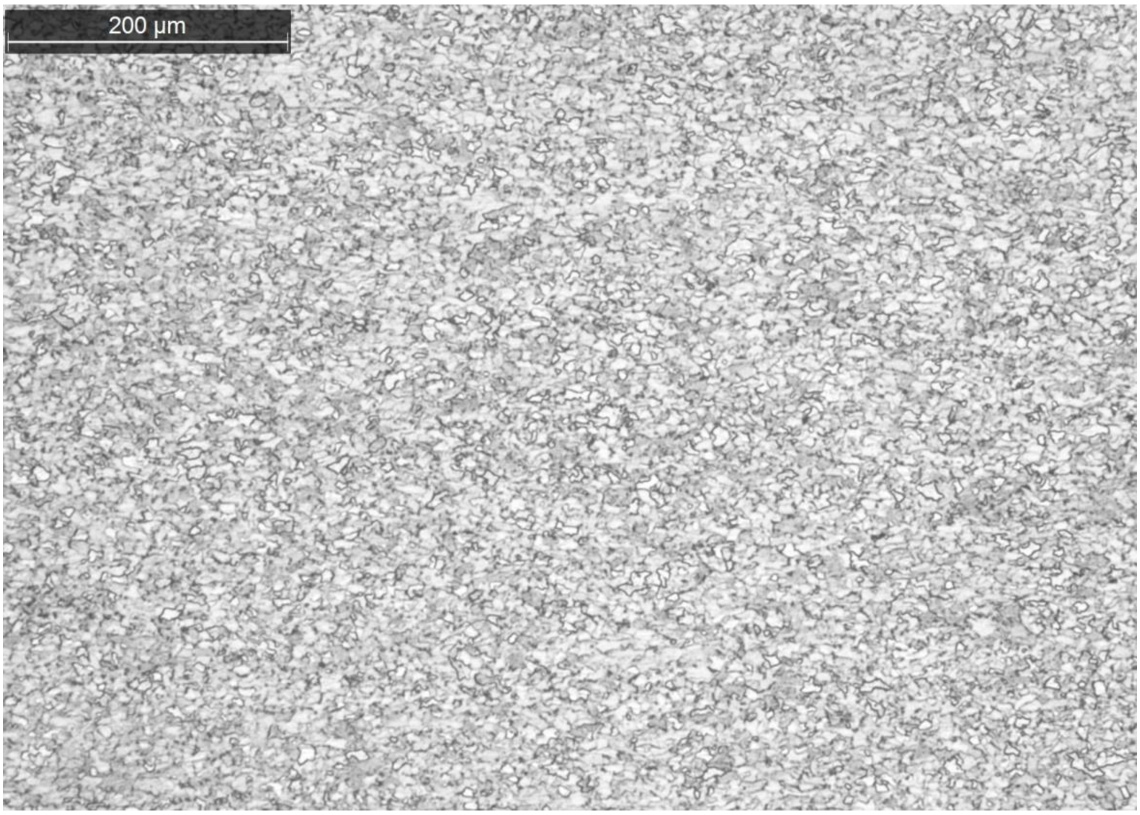

Figure 25 – S355MC zoom 100X

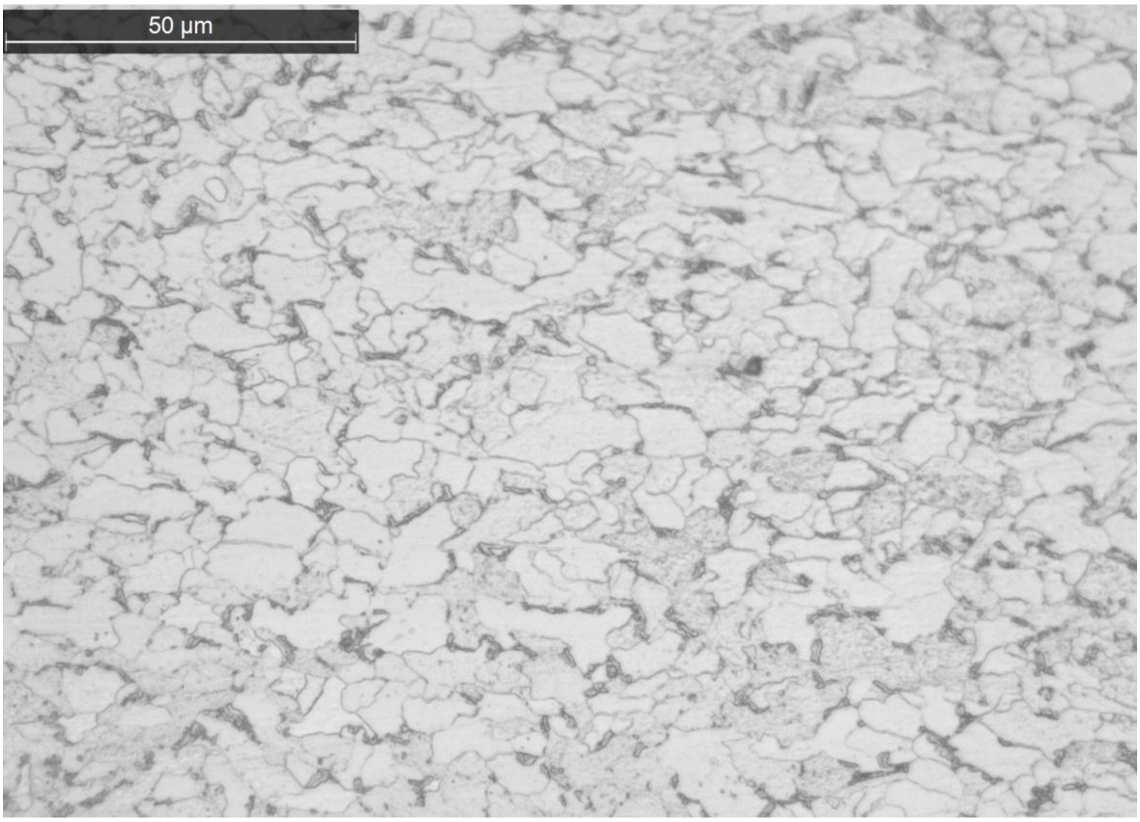

Figure 26 – S355MC zoom 500X

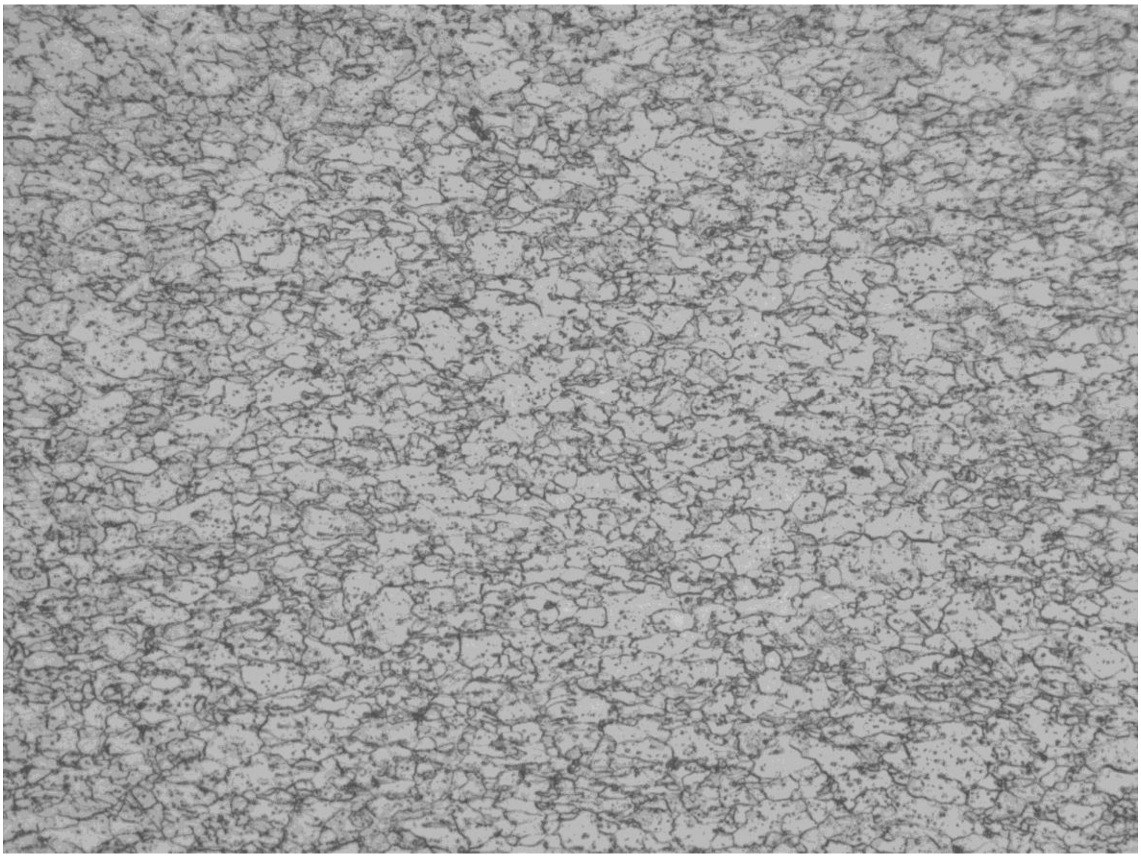

Figure 27 – HC380 zoom 200X

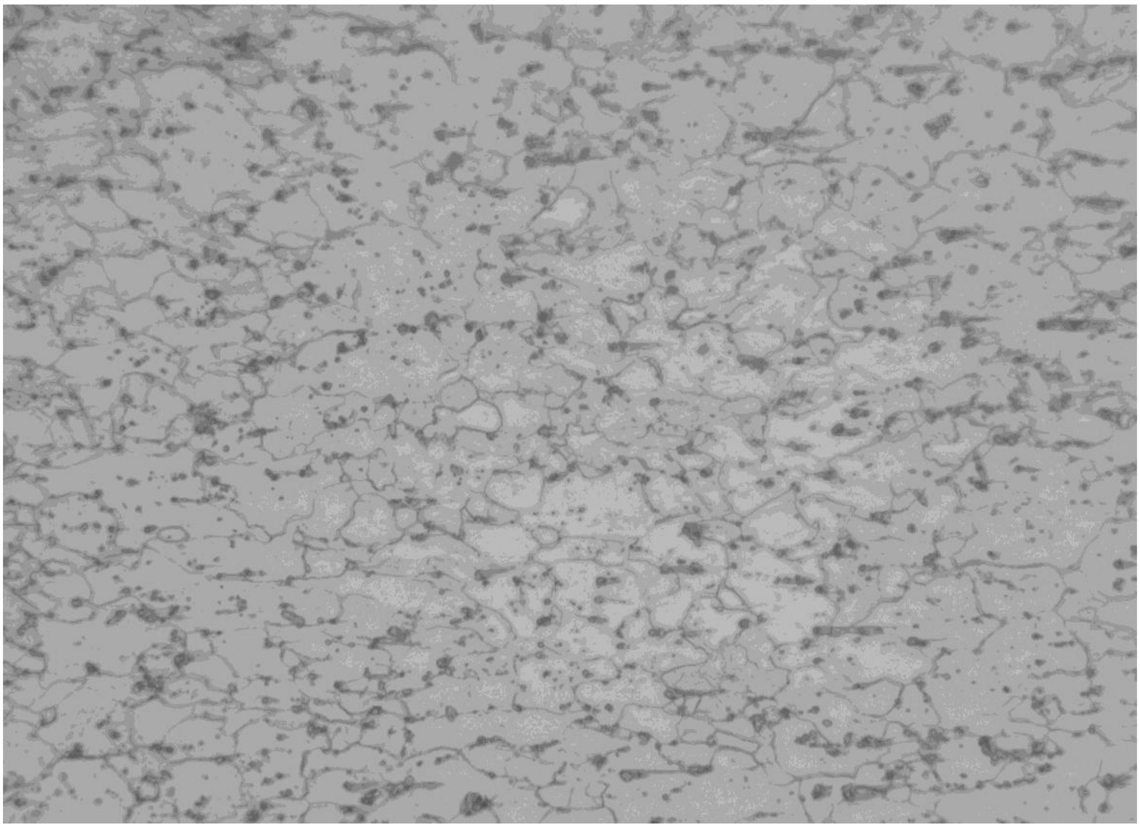

Figure 28 – HC380 zoom 500X

5 Conclusion

From the results of investigation on the effect of heat treatment on mechanical properties and microstructure of the various steel grades as mentioned above , the following conclusions were made:

Tensile strength, yield strength and hardness of medium carbon steel increased with plastic deformation while ductility and impact strength decreased due to strain hardening effect.

Normalization treatment had also resulted in higher tensile strength and hardness than annealed samples. This treatment is recommended as final treatment after manufacturing.

The tempered samples gave an increase in tensile strength and hardness than untreated sample as a result of formation of tempered martensite and resultant ferrite structure that were obtained.

Hardened sample had the highest tensile strength and hardness with lowest ductility and impact strength when compared to other heat treated samples. Hardening is strongly recommended when the strength and hardness are the prime desired properties in design.

The mechanical properties of steel can be altered through various heat treatments. The results obtained confirmed that improvement in mechanical properties that can be obtained by subjecting steel to different heat treatments investigated in this study.