Normalizing Processes Parameters Effects on the Microstructure and Mechanical Propertiesof Carbon SteelIS 2004Gr45C8

Santosh Kumar Maurya[1], Deepesh Bhavsar[2], Dr. Rahul Singh[3]
[1]*MTech scholar, Department of Mechanical Engineering RNTU, Bhopal, India*
[2]*Asst. Professor, Department of Mechanical Engineering RNTU, Bhopal, India*
[3]*HOD, Department of Mechanical Engineering RNTU, Bhopal, India*

***Abstract*-The carbon steel IS 2004 Gr45C8 has all suitable mechanical properties and is easy to use for anypurpose. Heat Treatment is a very important process to maintain the mechanical properties of steel like hardness, tensile strength, toughness, and ductility. Normalizing is a very important process of heat treatment and that is achieved in this paper. The normalizing process is a combination of three steps:**
(1) Gradually heating of specimen to the desired temperature
(2) soaking of specimen in the furnace at a defined temperature
(3) Air cooling. Specimen size is according to ASTM A370. With the increase in soaking temperature strength of the material decreases.

***Index Terms*:- IS 2004: 45C8, ASTM, Heat Treatment, Normalizing, and Microstructure.**

1.INTRODUCTION

Steel is arguably the world's most "advanced" material. It is a very versatile material with a wide range of attractive properties which can be produced at a very competitive production cost. It has a diverse range of applications and is second only to concrete in its annual production tonnage. Steel is an alloy of iron and carbon containing less than 2 weight percentage of C [1]. Further alloying elements introduce complexity to steel as the iron-carbon alloy system is enriched. As the alloying content of iron-carbon alloys is optimized, different mechanical and heat treatments can be employed, which offers a great number of possibilities for parameter alterations, and these are perpetually being explored. The high-strength steel category has been under constant research over the last few decades. Increasingly, these steels are used in various applications, including bridges, pipelines, cranes, and submarines as new and greater challenges are presented for designers and engineers. By using such steels, it can be possible to construct structures with shorter structural thickness and weight, as well as the same load-bearing capacity.

Carbon steel is defined as steel that has its properties mainly due to its carbon content and it does not contain more than 0.5% of silicon and 1.5% of manganese. The plain carbon steels varying from 0.04% carbon to 1.5% carbon are divided into the following types depending upon the carbon content.

1. Dead mild steel: — up to 0.15% carbon
2. Mild steel or Low carbon: — 0.15% to 0.45% carbon
3. Medium carbon steel: — 0.45% to 0.8% carbon
4. High carbon steel: — 0.8% to 1.5% carbon

1.2 HEAT TREATMENT METHODS & BENEFITS

Heat treatment is the procedure of heating and cooling metals, using specific predetermined methods to obtain preferred properties. Both ferrous and non–ferrous metals undertake heat treatment before placing them to use. Over time, a lot of different methods have been developed. For that, they develop new schedules or cycles to produce a variety of grades. Each schedule refers to a different rate of heating, holding, and cooling the metal. [1-6]

Benefits

There are various explanations for carrying out heat treatment. Some processes make the metal soft, while others increase hardness. They may also mark the electrical and heat conductivity of these materials. Some heat treatment methods relieve stresses induced in earlier cold working processes. Others develop desirable chemical properties to metals. Choosing the perfect method to get one metal with the essential properties. A metal part may go through several heat treatment procedures in some cases.

2. LITERATURE REVIEW

A few attempts have been made in the last decade to investigate heat treatment scrutiny experimentally and theoretically. In the following, we will discuss the heat treatment analysis that has been completed primarily. The work that took place is compared with the literature survey.

Yassin Mustafa Ahmed [7],A study of the effects of normalizing and annealing on carbon steel's chemical composition and mechanical properties ASTM A285GrC. An investigation of the degradation of mechanical properties of carbon steel specimens due to annealing and normalizing. This study described the impact of temperature changes on specimen mechanical properties. This paper presents two major heat treatment processes: annealing (or re-annealing of specimens) and soaking (or cooling) inside a furnace. Annealing requires progressively heating specimens in a furnace to 723degrees Celsius, soaking in the furnace, and cooling inside the furnace. "Normalizing" is another process that brings the specimens gradually above 723 degrees Celsius in a furnace and then soaks them in the furnace before cooling in the air.At 1000°C, the specimens' strength reached around 350 MPa after the annealing process was increased up to a certain temperature. It was discovered that the heat treatment process caused the specimen to lose some of its chemical composition when compared with the nominal composition.

GanwarichPluphrach [8],Examined the results from quenching of plain low-carbon steels in terms of mechanical properties and microstructure.After heating to 1000-1200°C for 4-6 hr and quenching with water, the grain size of the plain low-carbon steels was determined according to the ISO 643 standard. The reason that so many trials have comparable grain sizes is the heating temperatures were too high, causing the austenite to retard grain growth and recrystallization. An overheated material develops a coarse-grained structure, and such a structure is mechanically unsound. The Vickers hardness estimate was found to be well correlated with grain size.

FryadJaha Mahmud [9],A study was conducted on the impact of heat treatment on the mechanical properties of steel type SG 255. Their temperature selection for annealing (850, 900, and 950°C) was carefully considered.After testing the specimen until the fracture occurs, the mechanical behavior was verified by tensile testing.Result comparison with local industrial data was conducted. So they observed that it is possible to achieve a higher elongation level of around 34 % with a lower annealing temperature of 900 ^{0}C and this leads to a reduction in production costs without reducing the other properties of the material.

Al-Qawabah [10], by using low carbon steel to study the influence of different annealing temperatures on the mechanical features, microstructure, micro-hardness, and impact toughness. In specific, they used numerous temperatures for annealing 820,860, 900, and 940˚C. The impact of energy has been found to increase as the temperature of the annealing increases; the average is 22.5 percent which has been grasped at 820˚C. It was found that the micro-hardness decreased as the annealing temperature increased except at 940˚C, the peak decrease was 31.6 percent, which was reached at 900˚C.

PradipAndDahiwade [11],By annealing and normalizing steel, we studied how steel hardness affects hot rolling.Due to the rapid cooling rate in normalizing rather than annealing, it appeared that the steel hardness of the specimen was greater after normalization. Contrary to annealed steel, the specimen microstructure of uniform steel contains finer grains.

ObiukwuOsita [12],In this study, different heat treatment procedures (annealing, normalizing, tempering) were investigated as influencers of the mechanical properties of 0.35% carbon steel. As a result of conducting tensile, impact, and hardness tests, we found that mechanical properties change depending on the heat treatment condition. A study of steel microstructures was also conducted.Taking this paper as a whole, we can derive the conclusion that fatigue strength increases directly proportionately with tensile strength.

A. Babakhani [15], We investigated the microstructure and mechanical properties of commercial vanadium micro-alloyed forging steel (30MSV6) by varying the hot forging parameters (deformation temperature, strain, and cooling rate). Optical microscopy, Charpy impact, Brinell hardness, yield, and tensile testing were conducted to examine the microstructures and mechanical properties.Increased cooling rate results in an acicular ferrite-bainite microstructure, unlike ferritic-pearlitic microstructure. The results demonstrate that by increasing the forging post-cooling rate, yield, and ultimate tensile strength increase while the impact energy is reduced significantly. It is not only the deformation temperature that differs among the specimens with the same cooling rate but also the grain size that is determined by the ratio of deformation.

DigvijayNath Dubey [16], In forged steel billet for axle production, the effect of normalizing temperature and time on microstructure and variation in mechanical properties was examined. This process involves heating metals below their melting point and then cooling them outdoors to make them more ductile and reduce stress. As a result, the microstructure of the metal is also altered. The forged rear axle was normalized in our experiment by applying a normalizing process at a temperature of 870- 880 C and for two hours and 20 minutes to allow Good Growth of Ferrite and Pearlite PhasesNormalizing temperatures are found to decrease hardness and strength as well as normalizing temperatures increase. When it is heated to 870-880 C, ferrite and pearlite form a more uniform microstructure.

Shaping LU [17], Various normalizing processes of an Nb-bearing weld metal have been evaluated for their microstructure and mechanical properties. It was found that the as-welded and as-normalized weld metals were significantly different in their microstructure and mechanical properties. As welded, the weld metal exhibited a columnar grain structure. However, after 920°C normalizing treatment, the weld metal was converted to the equated grain, which was evident in the degenerated pearlite and NbC precipitates. Corresponding to the microstructure, the normalized weld metal had lower yield and tensile strengths, higher elongation, and higher impact energy than the as-welded weld metal. The grain size remained almost constant in the weld metal while the NbC precipitates in the weld metal increased with the prolonged holding time at the normalizing temperature of 920°C. The amount of NbC particles in the weld metal decreased with an increase in normalizing temperature and the proportion of Widmanstatten ferrite morphological structure increased, which resulted in a significant increase in yield and tensile strengths, but a decrease in elongation and impact toughness. In the Widmanstatten ferrite, the twin sub-plates were formed when normalized at 200°C, due to the dissolution of the NbC particles.

Triratna Shrestha [18], Heat treatment affects the microstructure and hardness of steel grade 91. A steel grade 91 (modified 9Cr1Mo steel) might be used in nuclear reactor pressure vessels up to 650 degrees Celsius in Next Generation Nuclear Power Plants.This study aimed to determine the heat treatment characteristics of steel Grade 91 after it was normalized and tempered for various periods of time. Micro-hardness profiles and calorimetry plots have also been used to study microstructural evolution in steel, including precipitate structures.Several thermodynamic calculations were conducted to support the experiment.Using the carbon isopleth and temperature dependence, the volume fraction of precipitates were also analyzed.

3. EXPERIMENTAL PROCEDURE

It was shown how the mechanical properties and grain size microstructures of medium-carbon steels were affected by various heat treatments. A study of the relationship between the temperature-time of the heat treatment process, the microstructure, and mechanical properties is presented here.

3.1 MATERIAL AND SPECIMEN PREPARATION

A medium carbon steel (45C8) is investigated for its microstructure, hardness, and sliding wear after heat treatment. The forging process produces this material, so it needs to be heat-treated for use in industries.

Fig 3.1 Medium Carbon Steel

The chemical composition of medium carbon steel IS 2004 Gr. 45C8 and the specimen used for the experiment are mentioned in Table-1. Required mechanical properties of IS 2004 Gr. 45C8 are mentioned in Table-2.

Table-1: Chemical Composition of medium carbon steel IS 2004 Gr. 45C8

Elements	Mn%	C%	Si%	P%	S%	Cr%	Ni%	Mo%	Fe%
Standards chemical composition	0.600 – 0.900	0.400 – 0.500	0.150 – 0.350	0.000-0.040	0.000 – 0.040	-	-	-	Balance
Specimen chemical composition	0.780	0.440	0.312	0.024	0.025	-	-	-	Balance

Table-2: Required Mechanical Properties of medium carbon steel IS 2004 Gr. 45C8

Ultimate Tensile strength	Yield Strength	Elongation %	Hardness
620	320 MPa min.	15 minimum	175 HB minimum

From the investment casting process, medium carbon steel of IS 2004 Gr45C8 has been used to prepare the specimens for this study. The specimen should then be heat-treated according to the size of the bar. Cut the small part of the bar for microstructure and hardness tests. Then machined the bar as per the following Fig the dimension of this casting test bar is according to table 3. Mark the gauge length and the diameter D of the sample after machining.It is now time to test it.

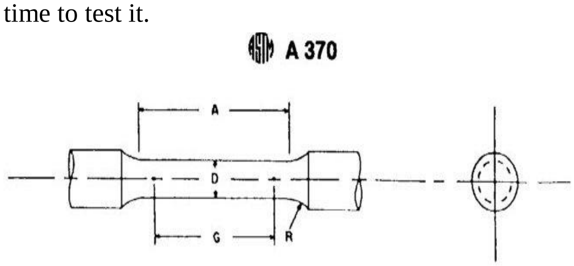

Fig 3.2 Specimen of medium carbon steel (45C8)

Table – 3, Basic Dimension of Specimen

Specification	Dimension	Calculation
Diameter (D)	16.00 ±0.12	Yield Strength = Load at Yield Point / A_i
Gauge Length (G)	80.00 ±0.10	Elongation % =((FL – G) / G) X 100 FL = Final gauge length.
Length of reduced section (A)	32.00 Min.	Reduction in Area % = ((A_i– A_f) / A_i) X 100 Final area $A_f= \pi D_f^2 / 4$,D_f = Final Diameter

3.2 HEAT TREATMENT PROCESS-

Heat Treatment of 45C8 was conducted and studied. The normalizing process was performed at different temperatures of 860 C, 900 C, 930 C, 960 C, and 1000 C with one hour of soaking after each.

We designed and built a twin conveyor system that precisely controlled cooling rates and controlled homogeneity during cooling. Temperatures were measured after specimens exited the furnace, as well as after they exited the conveyor, with a calibration pyrometer. The same pyrometer was also used to record the temperature of the billets during deformation.

For this experiment, we took a bar with a diameter of 16.00 mm with a flange made of forgings. The soaking temperature was set to 860 ˚C was set. Using the furnace's hydraulic pusher, one piece of steel bar was loaded into the tray and pushed by the hydraulic pusher. Material passed through a heated chamber at 750 degrees Celsius. After that, the material passed through the heating zone which is the soaking zone and the temperature of the soaking zone was 860 ˚C. After completing the soaking time, the material is removed from the furnace and slowly cooled in the air. In this paragraph, we discuss the microstructure of the piece after the piece was soaked at different temperatures. The soaking time is given to the piece at which best microstructure as Ferrite and Pearlite was achieved as 1 hour. After normalizing the piece, the micro-sample was cut from the flange side. By normalizing the material at different cycle temperatures, you can compare the microstructure, as shown by the following:-

Temperature = 860 ˚C, Cycle Time = 1.0 hours
Temperature = 900 ˚C, Cycle Time = 1.0 hours
Temperature = 930 ˚C, Cycle Time = 1.0 hours
and so on.

4. RESULT REPORT AND DISCUSSION

In this section, we describe the mechanical properties and microstructure of IS 2004 Gr45C8, as well as the effects of the heat treatment.

4.1 MICROSTRUCTURE STUDY

Normalizing:By normalizing the metal, the grain size and distribution become more uniform and ductile. As-cast specimens of 45C8 are depicted in Fig-1 (A) This picture does not show any heat treatment. This image shows ferrite plates embedded in pearlite matrix and grain boundary ferrite.

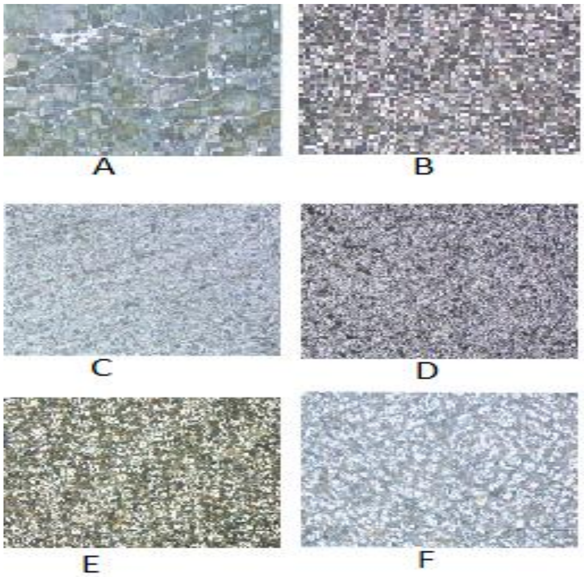

Fig-4.1: Microstructure (magnification: 100X) of 45C8 specimen (A)Without heat treatment (B)Normalizing at 860˚C (C)Normalizing at 900˚C (D) Normalizing at 930˚C (E)Normalizing at 960˚C (F) Normalizing at 1000˚C

Fig (4.1) shows the microstructure of the 45C8 sample after normalizing at 860˚C, 900˚C,930˚C,960˚C, and 1000˚Cwith a soaking time of one hour followed by air cooling.

4.2HARDNESS TEST:

Among the properties of hardness are cutting resistance, scratch resistance, abrasion resistance, and bending resistance. An object's hardness indicates its ability to resist plastic deformation, often caused by penetrationMetal properties are altered by heat treatment. A Brinell Hardness testing machine was used to determine the specimen's hardness. Based on a conversion table, the measurement was converted from HRB to HB.

Fig-4.2: Rockwell/Brinell Hardness Tester.

Table-4 The result obtained in the hardness test is mentioned in Table

Sr. No.	Specimen with heat treatment	Soaking time	Avg. Hardness (HB)
1	Normalized at 860 ˚C	1 hour	260
2	Normalized at 900 ˚C	1 hour	220
3	Normalized at 930 ˚C	1 hour	190
4	Normalized at 960 ˚C	1 hour	150
5	Normalized at 1000 ˚C	1 hour	140

4.3TENSILE TEST:

A material's tensile strength is calculated by dividing its cross-section area by the maximum load that it can bear when being stretched without fracture. This property is extremely important for the durability of the material. UTM is used for testing this property.

Fig-4.3: Tensile Testing by UTM

Fig-4.4 is displaying the Stress-Strain curve of a specimen normalized at 860˚C. The result obtained in a tensile test is that the value of tensile strength is 0.739 KN/mm² or (739 MPa). Elongation % is14.00%.

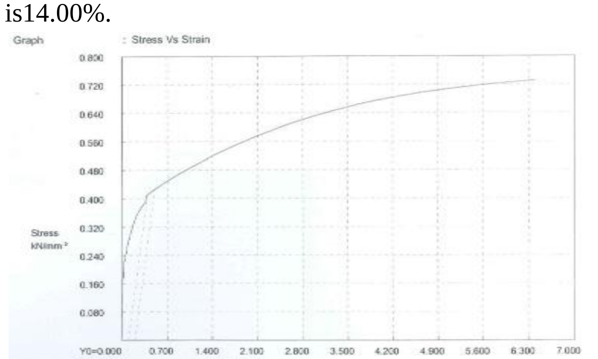

Fig-4.4: Stress-Strain curve of a specimen normalized at 860˚C

Fig-4.5 shows the stress-strain curve of a specimen normalized at 900 ˚C. Results obtained in a tensile test that the value of tensile strength was 0.665 KN/mm² or (665 MPa). Elongation% is 24%. Compare this result to the result of the specimen normalized at

860˚C. Tensile strength reduced this is because of the increased normalizing temperature. So the material will be more ductile.

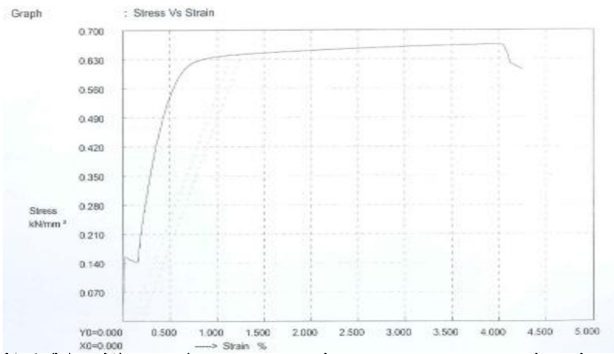

Fig-4.5: Stress-strain curve of a specimen normalized at 900 ˚C

Fig-4.6 shows the stress-strain curve of the specimen normalized at 930 ˚C. Results were obtained as 0.664 KN/mm² or (664 MPa). Elongation% 24%. Tensile strength decreased by 1 MPa but elongation% is the same at 24%.

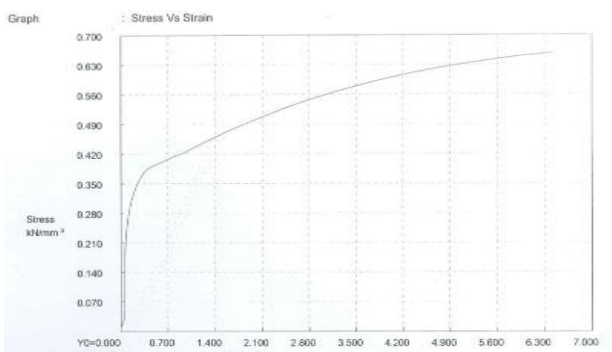

Fig-4.6: Stress-strain curve of specimen normalized at 930 ˚C.

Fig-4.7 shows the stress-strain curve of a specimen normalized at 960 ˚C. Results obtained in a tensile test that the value of tensile strength was 0.541 KN/mm² or (541 MPa). Elongation% is 24%.

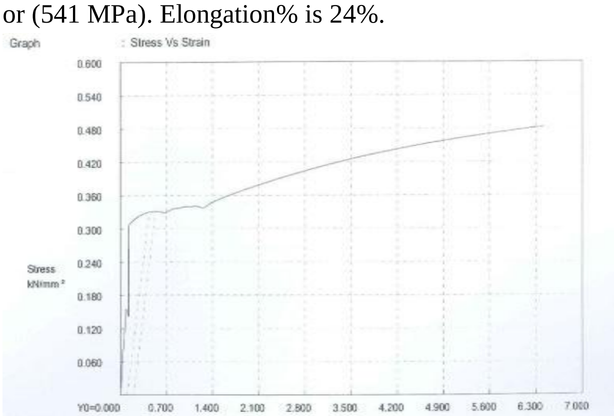

Fig-4.7: Stress-strain curve of a specimen normalized at 960 ˚C

Fig-4.8 shows the stress-strain curve of the specimen normalized at 1000 ˚C. Result obtained a tensile strength of 0.508 KN/mm² or (508 MPa). Elongation% 26%.

.

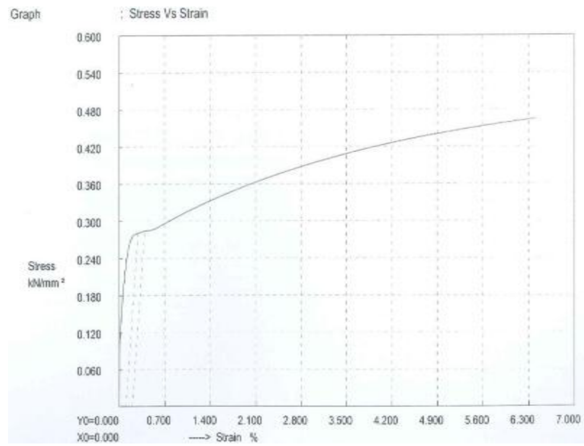

Fig-4.8: Stress-strain curve of specimen normalized at 1000 ˚C.

5. CONCLUSION

The experiment is conducted on specimens of material IS 2004 Gr45C8 steel in this work. The following conclusions can be drawn when evaluating the effects of normalizing heat treatment on IS 2004 Gr45C8 steel metal properties:

- A grain boundary ferrite structure is observed before heat treatment in the microstructure in the form of plates into pearlite matrix. Microstructures are normalized at 860 C, but the pearlite matrix is not broken completely after ferrite and pearlite are normalized. Microstructures of ferrite and pearlite are fine after normalizing at 900 C. The ferrite and pearlite fine grains were observed once again after the normalizing process at 930 C. But after normalizing at 960˚C grain structure become coarse. We repeated the normalizing procedure at 1000 °C, this time based on the coarse grain structure.
- A decrease in hardness is evident during testing when the normalizing temperature increases.During normalization, the material's microstructure shifted from brittle to ductile.
- As the normalizing temperature increases, the tensile strength of the specimens decreases. So we can

conclude that, after the normalizing process. As a result, we have reached the following conclusions:

1. It is recommended that IS 2004 Gr45C8 be normalized at 900 C to 930 C, followed by soaking and air cooling for a period of one hour.
2. During normalization at 900°C and 930°C, fine-grained ferrite and pearlite were found to be present.
3. 900 C and 930 C normalized tensile strength values were good.
4. 900 °C and 930 °C were used to normalize for the hardness value.

REFERENCE

[1] ASM;Subject Guide Heat Treating, 2015.

[2] ASM; Metals Hand Book, Volume 4, Heat Treating,2009.

[3] EPRI, Electric Power Research Institute; "Carbon Steel HandBook, 2007.

[4] ASME 2007 BPVC Section IX - Welding and BrazingQualifications, 2007.

[5] ASM Handbook; Properties and Selection Irons Steels andHigh-Performance Alloys,2009.

[6] American Society for Metals, ASM; Practical Heat Treating,2010.

[7] Yassin Mustafa Ahmed "The Influence of Annealing and Normalizing Processes on the Mechanical Properties and Chemical Composition of Carbon Steel ASTM A285Gr.C" International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-5, January 2020.

[8] Ganwarich Pluphrach1 and Tanee Aomor2 "Mechanical Properties and Microstructure of Plain Low-Carbon Steels after Quenching" RESEARCH AND DEVELOPMENT JOURNAL VOLUME 19 NO.2, 2008.

[9] B. A. H. S. Fryad J. Mahmud, Kawan M. Abdulrahman, Hawker J. Muhammed, "The Influence of Annealing Temperature and Soaking Time on the Ductility of SG 255," Kurdistan J. Appl. Res., vol. 2, no. 3, 2017.

[10] U. F. A.-Q. S.M.A. Al-Qawabah, NabeelAlshabatat, "Effect of Annealing Temperature on the Microstructure, Microhardness, Mechanical Behavior and Impact Toughness of Low Carbon Steel Grade 45," Int. J. Eng. Res. Appl., vol. 2, no. 3, pp. 1550–1553, 2012.

[11] S. S. N. K. S. PradipA.Dahiwade, "Study the effect of hardness of steel by Annealing and Normalizing during hot Rolling Processes," Int. J. Innov. Res. Technol., vol. 1, no. 2, pp. 12–17, 2014.

[12] U. P. ObiukwuOsita, Udeani Henry, "The Effect of Heat Treatment on the Mechanical Properties of SAE 1035 Steel," Int. J. Eng. Technol., vol. 8, pp. 32–43, 2016.

[13] A. A. R. and B. T. S. Yassin Mustafa Ahmed, Hameed D. Lafta, "Experimental Study of the Performance of Base Metal and Welding Line of the Household LPG Cylinder Manufactured in Kurdistan Region.," Int. J. Eng. Mater. Manuf., vol. 4, no. 3, pp. 116–123, 2019.

[14] V. B. da TrindadeFilho A. S. Guimarães and J. da C. PayãoFilho "Normalizing Heat Treatment Effect on Low Alloy Steel Weld Metals" J. of the Braz. Soc. of Mech. Sci. & Eng. January-March 2004, Vol. XXVI, No. 1.

[15] A.Babakhani a, A. R. Kiani-Rashid a & S. M. R. Ziaei a "The Microstructure and Mechanical Properties of Hot Forged Vanadium Microalloyed Steel" http://dx.doi.org/10.1080/10426914.2011.557 287

[16] 1Digvijay Nath Dubey, 2Rupesh Bharti "Normalizing Temperature and Time Effect on Micro Structure and Change in Mechanical Properties of Forged Steel Billet for Axle Production" International Journal of Innovative Science and Research Technology ISSN No:-2456-2165 Volume 4, Issue 5, May– 2019.

[17] Shanping LU, Shitong WEI, Zhiquan LIU, Dianzhong LI and Yiyi LI "Effects of Normalizing Process on the Microstructural Evolution and Mechanical Properties of Low Carbon Steel Weld Metal with Niobium Addition" ISIJ International, Vol. 50 (2010), No. 2, pp. 248–254.

[18] Triratna Shrestha 1, Sultan F. Alsagabi 1, IndrajitCharit 1, Gabriel P. Potirniche 2 and Michael V. Glazoff 3 "Effect of Heat Treatment on Microstructure and Hardness of Grade 91 Steel" metals ISSN 2075-4701 www.mdpi.com/ journal /metals Received: 4 December 2014 / Accepted: 12 January 2015 / Published: 21 January 2015

[19] D.G.R.WilliamD.Callister,Jr., Materials Science and Engineeringan Introduction-8theEd-2010-Callister., EIGHT.JohnWiley&Sons,Inc., 2010.

[20] American Society for Testing and Materials, ASTM-A 285 -A 285M-12. Standard Specification for Pressure Vessel Plates,Carbon Steel, Low- and Intermediate-Tensile Strength,2007.

[21] L.-E. Svensson: Control of microstructure and properties in steel arc welds, CRC Press, Inc., 1994

[22] K. Easterling, Introduction to the Physical Metallurgy of Welding, Butter -worths& Co Ltd., 1983.

[23] T. Edvardson, H. Fredriksson& I. Svensson, Met. Sci. 10, 298, 1976.

[24] E.S. Davenport and E.C. Bain, Trans. Met. Soc. A.I.M.E. 90, 117, 1930.

[25] Electron microstructure of Bainite in Steels, 2nd Progress Report by Subcommittee XI of Committee E-4, ASTM Proc. 52, 543, 1952.

[26] H.K.D.H. Bhadeshia, Some phase transformations is steel. Material Science and Technology, 1999. 15: p. 22 - 29.