Sivam et al. 2019. *Int. J. Vehicle Structures & Systems*, 11(1), 15-20
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.11.1.04

**International Journal of**
**Vehicle Structures & Systems**
Available online at www.maftree.org/eja

# Study on Microstructural Characteristics and Mechanical Behaviour of AISI1050 Steel under Various Heat Treatments

**S.P. Sundar Singh Sivam[a,b], Ganesh Babu Loganathan[c], V.G. Umasekar[a,d], P.S. Suresh Kumar[e] and Saravanan Raja[f]**

*[a]Dept of Mech. Engg., SRM Institute of Sci. and Tech., Kattankulathur, Tamil Nadu, India*
*[b]Corresponding Author, Email: sundar.sp@ktr.srmuniv.ac.in*
*[c]Dept. of Mechatronics Engg., ISHIK University, Kurdistan Regional Government, Erbil, Iraq*
*Email: ganesh.babu@ishik.edu.iq*
*[d]Email: umasekar.g@ktr.srmuniv.ac.in*
*[e]Research & Development, Materials Engg. Dept., Renault Nissan Tech. Business Center India Pvt Ltd, Chengalpattu, Tamil Nadu*
*Email: metsuresh208@gmail.com*
*[f]Quality Assurance and Control, NTN NEI Manufacturing India Pvt Ltd, Chennai, Tamil Nadu*
*Email: saravanan.raja87@yahoo.com*

## ABSTRACT:

*Heat treatment of metal alloys is one of the most widely used techniques for achieving the desired mechanical properties by modifying the microstructure namely the grain and or by altering the second phases present in heat treat able alloys. At times heat treated materials undergo further process like forming, machining, welding etc. Thus the present work describes the effect of heat treatment of AISI 1050 steel and its associated micro structural changes that correlate it with the mechanical behaviour. AISI 1050 steel is widely used in the production of bearings, landing gear, actuators and aerospace structural components. In this study, different samples of AISI 1050 steel were heat treated to temperature above the austenitic region and were subjected to annealing or normalising, or spheroiding. It is indicative that the properties of the AISI 1050 steel can be easily altered by heat treatment to suit a particular application and for secondary processing. The property comparison includes micro structural grain size, yield strength, tensile strength, hardness and percentage elongation. Thus the results provide a better insight on the process of increasing the versatility of the AISI 1050 steel for its demanding use in aerospace structural applications and related mechanical processing. It was found that the effect of heat treatment has resulted in increased grain size, decreased strength and hardness, and improved properties which were more suitable for machining and forming process.*

## KEYWORDS:

*AISI1050 steel; Heat treatment; Micro structure; Mechanical properties*

## CITATION:

S.P.S.S. Sivam, G.B. Loganathan, V.G. Umasekar, P.S. Suresh Kumar and S. Raja. 2019. Study on Micro structural Characteristics and Mechanical Behaviour of AISI1050 Steel under Various Heat Treatments, *Int. J. Vehicle Structures & Systems*, 11(1), 15-20. doi:10.4273/ijvss.11.1.04.

## 1. Introduction

AISI 1050 steel is widely used in the production of bearings, landing gear, actuators and aerospace structural components. Heat treatment is procedure of changing the microstructure of metallic materials by heating the material to a particular temperature and then cooling it at a controlled rate to obtain desired structural properties [1-3]. It is conceivable to get the attractive mechanical properties for steel or combinations by heat treatment. In heat treatment temperature variety with time is essential parameter to adjust the mechanical property of the segment. This variety is appropriate with the goal that stage change is as per part application necessity, in light of the fact that the fundamental prerequisite of mechanical properties is diverse for various conditions [2-6]. The mechanical testing and characterization of materials is critical in mechanical design of structural component design.

Annealing, normalizing, spheroidizing, hardening and tempering are used to change the microstructure and mechanical properties of structural and building materials like steels. Annealing is characterized as a heat treatment that comprises of heating to a particular temperature and then holding at a temperature and then cooling it at suitable rate. Steel is an alloy of iron in which carbon is the major constituent element, with other elements added in small quantities to give desired properties. The other alloying elements added to the plain-carbon steel include nickel molybdenum, chromium and cobalt [5-12]. As the carbon content increases, the alloy becomes harder. The motivation behind heat treating carbon steel is aimed at changing the presence of the carbon atoms in the ferrite microstructure and thus to alter the mechanical properties of steel such as its hardness, percentage elongation, yield, and its modulus [10-18]. The heat treatment changes the hardness, tensile strength, yield strength, and ductility. These procedures additionally help to enhance machining impact, and make them flexible [13-18].

## 2. Experimental work

### *2.1. Materials*

AISI 1050 steel was purchased in the form of rods of 40mm diameter and 300mm length and specimens of were made as per ASTM A370 standard for tensile test and mechanical characterization. Specimens of 8mm ×8mm×8mm are used for microstructural analysis. The chemical composition of the AISI 1050steel used is given in Table 1.

**Table 1: AISI 1050 chemical composition**

| Alloying element (%wt) | C | S | P | Mn | Fe |
|---|---|---|---|---|---|
| AISI 1050 | 0.41 | 0.049 | 0.036 | 0.87 | Balance |

### *2.2. Methodology*

Standard tractable test specimens were produced from the purchased AISI 1050 steel using CNC lathe machine. The chemical composition tests were conducted as per ASTM E350. Mechanical property tests were conducted as per ASTM A370 for the specimens. All of the samples were subjected to different heat treatment operations like annealing, normalizing, and spheroidizing according to the industry standards. Heat treated specimens were investigated for microstructural changes and tested for mechanical properties. Once the chemical composition was determined, the specimens were heat treated in the heater for achieving the austenization temperature (925°C) of the material. At that point the particular heat treatment process like annealing, normalizing, and spheroidizing were made. The samples of AISI 1050 were prepared for mechanical properties test. For annealing, the specimen was annealed by heating the material upto the temperature of 925°C in a muffle furnace, holding it until the temperature is uniform throughout the specimen for 2hrs, and was slowly furnace cooled. For normalizing, the metal was heated in a muffle furnace at a temperature of 950°C. The material was kept at this temperature for 80 minutes, and then cooled to room temperature in still air. For spheroidizing, the metal was heated up to lower critical temperature (LCL) of 700°C - 750°C and held for 3 hours and was furnace cooled very slowly.

### *2.3. Microstructure examination*

Microstructure examination of the untreated and heat treated specimens were studied with the help of SEM image analysis. Each specimen was grounded carefully flat with the help of emery paper of decreasing coarseness to form a scratch free flat surface for microscopic examination under optical microscope. The emery ground surface of the samples were cleaned with alumina abrasives laiden micro clothe and followed by etching it with a solution containing 5% $CuCl_2$, 8% HCl, and 87% (95%$C_2H_5OH$ + 5%$CH_3OH$). For observing the microstructure under optical microscope, the specimens were mechanically wet ground and etched chemically in 5% aqua-regia solution for 10min. The grain structure and size was observed by SEM image analysis after electro-polishing the specimens with a 5% per chloric acid + 95% methyl alcohol in vol. % at voltage potential of 18Voltsand 0.5mA at temperature of 50°C to remove any strained surface resulted from mechanical polishing.

## 3. Results and discussion

### *3.1. Effect of heat treatment on microstructure*

The microstructure of un-treated specimen is shown in Fig. 1. It has the uniform distribution of Pearlite in the Ferrite matrix. The light (white) region corresponds to that of the ferrite matrix and the dark region (black) to that of the fine pearlite. Ferrite leads to a reduction in strength and hardness but high ductility and toughness. Whereas, pearlite structure provides higher strength in tension and reduced ductility of the material. These two provide a balance between ductility and strength of the material. The microstructure of annealed specimen is shown in Fig. 2. It shows the homogeneous distribution of banding structure of pearlite and ferrite due to the complete crystallization of ferrite particles which form the major portion of the microstructure. The composition is not so different from that of the untreated specimen but, at 910°C the deformed structure becomes completely homogenized in contrast with that of the uneven particle distribution in the untreated specimen. There is an absence of any bainite particles in the microstructure.

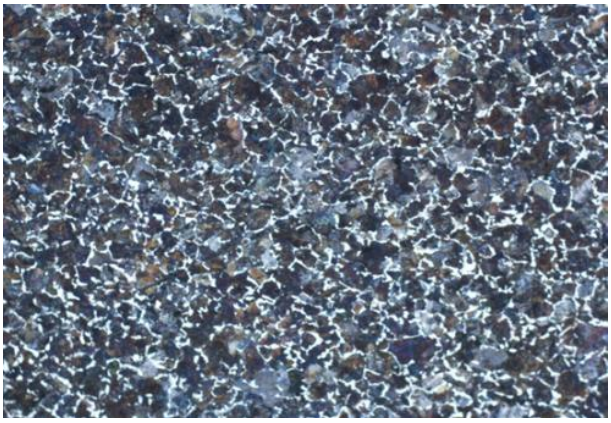

**Fig. 1: Microstructure of untreated AISI 1050**

**Fig. 2: Microstructure of annealed AISI 1050**

The microstructure of normalized specimen is shown in Fig. 3. It shows that the initial shape and size of the austenite grains were changed by a large extent. Graphite flakes were observed surrounded by uniformly distributed patches of dark pearlite particles. Austenite, produced by a combination of rapid cooling which suppressed the formation of pearlite and the super saturation of carbon. Compared to the ferrite present in the untreated specimen, the austenite matrix due to its large grain size provides higher ductility and toughness at all the heat treatment temperatures. Also unlike the untreated specimen, the presences of graphite flakes impart a decrease in the hardness of the material. There was an absence of a banding structure as seen in the annealed specimen. The sample consists of a pearlite matrix in which the graphite flakes were found to be shorter than in the annealed sample.

The microstructure of spheroidized specimen is shown in Fig. 4. It shows the presence of partially spheroidized cementite with ferrite matrix. The process of spheroidization is achieved by heating the materials at temperature that are slightly below the eutectoid temperature, followed by a slow cooling process. By heating at this temperature pearlite, gets converted to ferrite and cementite. As compared to the untreated sample, the particles in spheroidite are a many-fold larger size than those of pearlite and are spaced further apart. The resulting spheroidite structure is a microstructure that contains sphere-like cementite particles. The graphite present in the steel diffuses and reacts with carbon atoms to form spherical lumps of cementite, known as spheroidite. The spheroidite steel is extremely ductile compared to the untreated specimen. Apart from this no such bainite and lamellar pearlite were observed.

**Fig. 3: Microstructure of normalized AISI 1050**

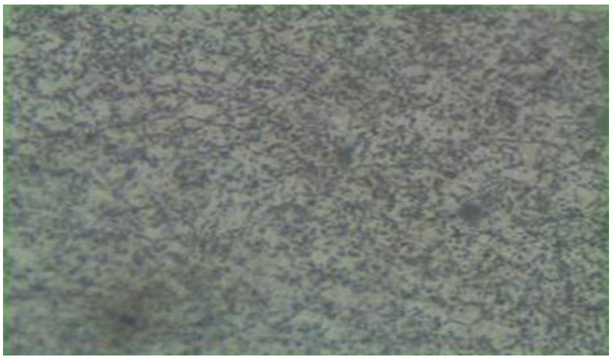

**Fig. 4: Microstructure of spheroidized AISI 1050**

### 3.2. Effect of heat treatment on grain size and mechanical properties

The effect of various heat treatments like annealing, normalising, and spheroidizing against the untreated specimens, was observed for the microstructural changes in grain size, and for the associated mechanical properties, like hardness, yield strength, tensile strength, and percent elongation. The untreated samples of AISI 1050 revealed an ASTM grain size number of 7, hardness value of269 HBW, tensile strength of 785MPa, percentage of elongation of 17 % and yield strength 646 MPa. These values are set as a base-line reference to compare the heat treated samples to quantify the effect of heat treatment and its effect on mechanical properties. The annealed AISI 1050 samples showed an increase in grain size to 8.5 ASTM, hardness to 201 HBW, tensile strength to 708 MPa, yield strength to 491 MPa and percentage of elongation to 23%. The increase in the grain size is due to the growth of the crystalline atoms at the grain boundary at elevated temperature and longer time. The internal stresses are also relieved as a consequence and thus reducing the strength by reducing the number of grain boundaries.

The decrease in yield strength, and tensile strength are due to reduced dislocation density by the reduction of grain size. Since hardness is a measure of plastic deformation, the hardness of the annealed sample consequently decreases as yield strength decreases. The ductility has increased due to atomic sliding on long range, and the formation of soft ferrite matrix. The normalized AISI 1050 samples show a slight increase in the grain size to 7.5 ASTM, hardness to 223HBW, tensile strength to 779 MPa, yield strength of 553 MPa, and an increase in the percentage elongation to 24%. The slight decrease in yield strength, and tensile strength are due to the slight increase in the grain size of the untreated sample. The decrease in the hardness is also a consequence of reduced yield strength, when compared with the untreated sample. Pearlite matrix structure was obtained by subjecting the steel to normalization. Whereas, normalized steel shows higher strength than the annealed samples.

The formation of soft and long pearlite matrix is responsible for the increased elongation percentage. The spheroidized specimens show a tremendous decrease in the grain size, un-comparable with the untreated specimen. This is due to the extent formation of relatively small globalized granular pearlite with ferrite matrix with no bainite and no lamellar pearlite. The hardness was 183HBW, tensile strength to 654MPa, yield strength to 569 MPa, and percentage elongation of 25%. Though the grain size is small and un-observable with the standard magnification of $100_x$, there is no increase in the yield strength, tensile strength; this is because of the formation of the soft spheroidal pearlite with no hard bainite. The spheroidal pearlite assists slip despite the very small microstructure observed. Thus hardness was less and ductility was more compared to the untreated steel. A plot of the variation in the values of the grain size of various heat treated samples along with the un-treated sample is shown in Fig. 5. The increase in the size of the grains by annealing and normalizing are due to the growth of grain by the re-arrangement of atoms at the grain boundary.

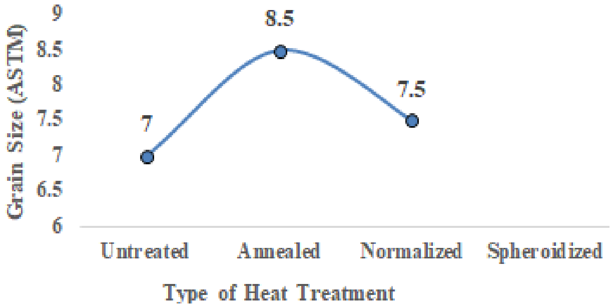

**Fig. 5: Grain Size variation of the AISI 1050**

A plot of the variation in the value of the hardness of various heat treated samples along with the un-treated samples is shown in Fig. 6. The hardness values decrease with heat treatment when compared with the untreated samples. The annealed specimen's hardness is less than that of the normalized specimen due to increased grain size. The spheroidized specimen showed least amount of hardness. Higher hardness was observed on the un-treated AISI 1050 specimens. Hardness of the steel increases both with pearlite content and with the rate of cooling. The reason being that martensite is the hardest form of structure and offers very high strength to the steel. The increase in hardness of the formation of pearlite and martensite, at a higher rate of cooling.

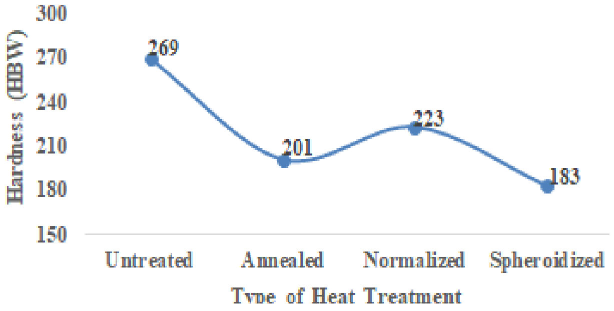

**Fig. 6: Hardness variation of the AISI 1050**

The variations in the value of tensile strength of the specimens are shown in Fig. 7. The value of tensile strength showed a decrease from that of the untreated specimen followed by the normalized specimen. The annealed specimen's tensile strength is less than that of the normalized specimen. The spheroidized specimen showed least amount of tensile strength due to the formation of the soft spheroidal pearlite structure. Fig.8 shows the variations in the values of the yield strength. The yield strength showed a decrease from the value of that of the untreated specimen followed by the spheroidized specimen. The normalized specimen's yield strength is less than that of the spheroidized specimen. The annealed specimen showed least amount of yield strength due to reduced dislocation density. Fig. 9 shows the variations in the value of percent elongation in tension, which were observed to be in the following order. The value of percent elongation showed an increase in magnitude from the value of that of the untreated specimen. The spheroidized specimen showed the highest percent elongation due to formation of spheroidal pearlite with no hard bainite structure, and value followed by the normalized specimen. The annealed specimen's percent elongation is less than that of the normalized specimen. The untreated specimen showed least amount of percent elongation.

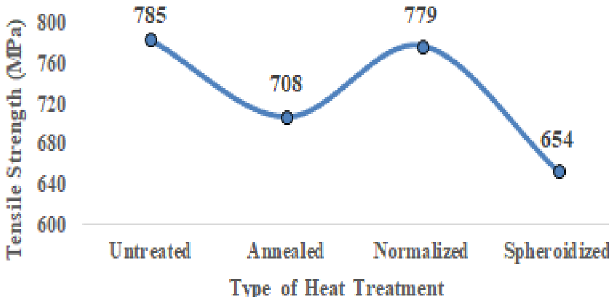

**Fig. 7: Yield Strength variation of the AISI 1050**

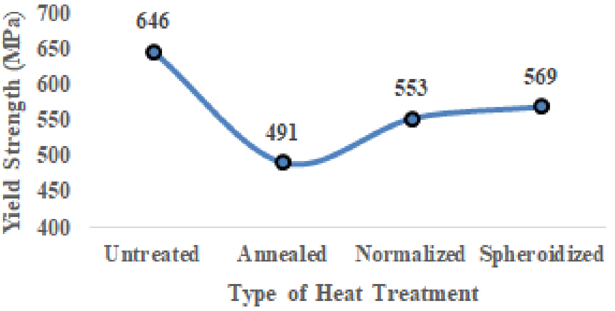

**Fig. 8: Tensile strength variation of the AISI1050**

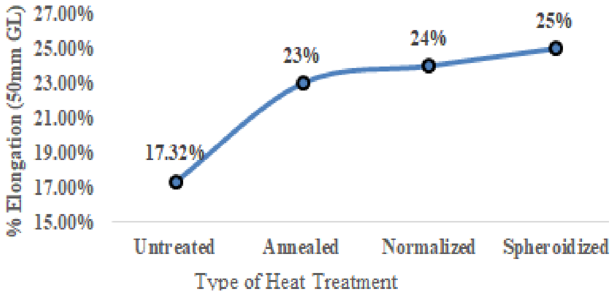

**Fig. 9: Percent elongation variation of the AISI 1050**

### *3.3. Effect of microstructure on manufacturing process*

For the selected specimen, there is a significant variation in material properties and phase distribution, pre and post the heat treatment in correlation with manufacturing process. In this case the hardness values of annealed, normalized and spheroidized specimens are lower than that of the untreated specimen. The spheroidized specimen is having the least hardness as compared to the untreated specimen and the normalized specimen's hardness value is closest to that of the untreated specimen. Hardness of the given material can be regarded as the most important factor affecting the machinability. In general terms, it is very easy to deduce that machinability is inversely proportional to the hardness of the material. More the hardness of the material, lower is the machinability and vice-versa. When hardness is taken into account for optimum machinability, it is found that for the given 21% carbon steel, the hardness range lies between 180-210 BHN, which is considered as optimum machinability hardness. But when the steel undergoes heat treatment process, there is a significant amount of variation obtained in terms of tool life which comes out to be different for annealing, normalizing and spheroidizing.

As compared to the untreated specimen's grain size, the spheroidized specimen's grain size is much bigger and the particles are far spaced from each other. Whereas the annealed and the normalized specimens have a grain size in an order which is relatively comparable to that of the untreated specimens. The grain sizes of the annealed and normalized specimens are greater than that of the untreated specimen. The grain size of the material also serves as general indicators of its machinability. The materials with small undistorted portions of grains were found. Those materials are classified as ductile materials. The materials of the grain size in an intermediate order represent a balance of machinability of both cutting and finishing. The hardness of the given specimens can be also correlated with its grain size to be used as an indicator of machinability. As compared to the untreated specimen's tensile strength, the spheroidized specimen's tensile strength is much low. However, the tensile strength of the normalized specimen is in close proximity of that of the untreated specimen. The value of tensile strength of annealed specimen is also less than that of the untreated specimen with a value approximately intermediate to that of the untreated and spheroidized specimens.

There is a change in the trend yield strength of the specimens taken into account. There is large decrease in the yield strength of the annealed specimen as compared to the untreated specimen. The yield strength of spheroidized and normalized specimens are found to be in close proximity, both having less values than that of the untreated specimen. The annealed specimen has the least yield strength. It is indicative that increased yield strength offers resistance of the material against plastic deformation, hence the increased hardness and reduced ductility. Higher the yield strength of the material, lower is the ease of machinability as cutting forces are also higher for hardened materials. A tensile test is used to establish both the yield strength and tensile strength for the given material based on the type of heat treatment performed. In case of tensile strength the ultimate strength is considered. There is a decrease in the tensile strength of the annealed specimen as compared to the untreated specimen. The normalized specimen has a value close to but less than the untreated specimen. The normalized specimen is followed by the annealed and spheroidized specimens with spheroidized specimen having the least value. The ease of machinability increases with the decrease in the tensile strength. The value of percent elongation of the annealed, normalized and the spheroidized specimens altogether lie in a close proximity to each other but all of these values are comparatively greater than that of the untreated specimen. The spheroidized specimen has the highest percent elongation followed by normalized and annealed specimens respectively. The untreated specimen has the least percent elongation. The increase in percentage of elongation of the material makes it easy for the tools to perform cutting operation on the specimens. Greater the percentage elongation of the specimen, higher is the ease of machinability.

## 4. Conclusions

The heat treated specimens indicate microstructural and mechanical properties conducive for better manufacturing process in terms of machinability as compared to the untreated specimen. A significant correlation between machinability and the corresponding mechanical properties of the specimens such as grain size, hardness, tensile strength, yield strength and percentage elongation could be observed. The optimum ease of machinability was achieved with the spheroidized specimen. The untreated specimen showed a microstructure of uniformly distributed pearlite corresponding to the dark regions and the ferrite matrix corresponding to that of the lighter region. The annealed specimen showed a microstructure of homogeneous banding of pearlite and ferrite. The grain size of the spheroidized specimen was found to be quite large as globalized structures as compared to that the untreated specimen. Only the annealed and normalized specimens had a grain size comparable to that of the untreated specimen. This shows the tremendous increase in the ductility of the spheroidized specimen as compared to the untreated specimen. The value of hardness was also observed to be maximum for the untreated steel specimen. The value of hardness, of the steel increases both with increase in the amount of pearlite and also with the higher rate of cooling, resulting in a fine microstructure compared to the untreated specimen.

## REFERENCES:

[1] M.F. Hasan. 2016. Analysis of mechanical behavior and microstructural characteristics change of ASTM A-36, steel applying various heat treatments, *J. Material Sci. Engg.*, 5(2), 1-6. https://doi.org/10.4172/2169-0022.1000227.

[2] K.A. Dell. 1989. *Metallurgy Theory and Practical Textbook*, American Technical Society, Chicago.

[3] V.B. John. 1980. *Introduction to Engg. Materials*, 2nd Ed., Macmillan Publishing Co. Ltd.

[4] A.J. Alawode. 2002. *Effects of Cold Work and Stress Relief Annealing Cycle on the Mechanical Properties and Residual Stresses of Cold-Drawn Mild Steel Rod*, ME. Thesis, Mech. Engg. Dept., University of Ilorin, Nigeria.

[5] K. Funatani and G.E. Totten. 1997. Present accomplishments and future challenges of quenching technology, *Proc. 6th Int. Federation of Heat Treatment and Surface Engg. Congress*, Kyongju, Korea.

[6] W.J. Nam and C.M. Bae. 1999. Coarsening behavior of cementite particles at a subcritical temperature in a medium carbon Steel, *Scripta Materialia*, 41, 313-318. https://doi.org/10.1016/S1359-6462(99)00168-2.

[7] V.K. Manchanda and G.B.S. Narang. 2005. *Materials and Metallurgy*, 6th Ed, Khanna Publishers.

[8] S.P.S.S. Sivam, V.G. Umasekar, M. Shubham, M. Avishek and A. Mondal. 2016. Orbital cold forming technology - Combining high quality forming with cost effectiveness - A review, *Indian J. Sci. and Tech*, 9(38), 1-7. https://doi.org/10.17485/ijst/2016/v9i38/91426.

[9] *American Machinist*. http://www.americanmachinist.com/cutting-tools/chapter-3-machinability-metals.

[10] *ASTM E18*. 2008. Standard test method for Rockwell hardness of metallic materials, American Society of Testing and Materials.

[11] *ASTM E8*. 2008. Standard test method for tension testing of metallic materials, American Society of Testing and Materials.

[12] M.H. Jokhio. 1991. *Effect of Retained Austenite on Abrasive Wear Resistance of Carburised SAE 8822H Steel*, Thesis in Manuf. Engg., Mehran University of Engg.& Tech., Jamshoro.

[13] S.P.S.S. Sivam, V.G. UmaSekar, K. Saravanan, S.R. Kumar, P. Karthikeyan and K. SathiyaMoorthy. 2016. Frequently used anisotropic yield criteria for sheet metal applications: A Review, *Indian J. Sci. and Tech*., 9(47), 1-6. https://doi.org/10.17485/ijst/2015/v8i1/92107.

[14] H.J. Hu, Z.Y. Zhai, Y.Y. Li, X.B. Gong and H. Wang. 2015. The simulation researches on hot extrusion of super-fined tube made of magnesium alloys, Russian *J. Non-Ferrous Metals*, 56, 196-205. https://doi.org/10.3103/S1067821215020066.

[15] X. Gong, H. Li, S.B. Kang, J.H. Cho and S. Li. 2010. Microstructure and mechanical properties of twin-roll cast Mg-4.5Al-1.0Zn alloy sheets processed by differential speed rolling, *Materials and Design*, 31, 1581-1587. https://doi.org/10.1016/j.matdes.2009.09.021.

[16] S.P.S.S. Sivam, A. Lakshmankumar, K.S. Moorthy and S.R. Kumar. 2015. Investigation exploration outcome of heat treatment on corrosion resistance of AA 5083 in marine application, *Int. J. Chemical Sci.,* 14(S2), 453-460.

[17] S.P.S.S. Sivam, M. Gopal, S. Venkatasamy and S. Singh. 2015. An experimental investigation and optimisation of ecological machining parameters on aluminium 6063 in its annealed and unannealed, *J. Chemical and Pharmaceutical Sci*., 9, 46-53.

[18] S.P.S.S. Sivam. 2017. Multi response optimization of setting input variables for getting better product quality in machining of magnesium AM60 by grey relation analysis and ANOVA, *Periodica Polytechnica Mech. Engg*., 62(2), 118-125. https://doi.org/10.3311/PPme.11034.