JOURNAL OF SCIENTIFIC RESEARCH IN ALLIED SCIENCES
ISSN NO. 2455-5800
Contents available at: www.jusres.com

LITERATURE REVIEW ON THE MECHANICAL PROPERTIES OF ANNEALED ALUMINIUM ALLOY

Ramakant Sao, S P Shrivas, Chandrakala Sao
Mechnaical engineering Department
CSVTU Bhilai

ARTICLE INFO **ABSTRACT** **REVIEW ARTICLE**

Article History
Received: March 2018
Accepted: April 2018
Keywords:
Annealing, Aluminum Alloy Al 5083, Properties, and Temperatures.

Corresponding Author
*Sao R.

Through the advent of newer technologies, search for new materials was started with the aim to fulfill various necessities needed in future and also search was aimed to improve material to suit the present necessities. Interpretation for the improvement of properties of various metals and alloys (ferrous and non- ferrous), it has been seen that heat treatment is the most effective way. In this investigation, we studied the mechanical properties of Aluminum alloy Al 5083 at different annealing temperature 350ºC, 400ºC, and 450ºC and saw how it affects different mechanical properties such as hardness, tensile strength, ductility and toughness of Aluminum alloy Al 5083.

Introduction

In general heat treatment basically modifies microstructures and thereby produces a variety of mechanical properties that are important in manufacturing, such as improved formability and machinability. Annealing is considered the most important heat treatment process as it helps to stabilize the microstructure.

Non-Ferrous Materials

This increase in demand for these alloys is because of their unique characteristics like corrosion resistance, lightweight, nonmagnetic and a good conductor of heat and energy. Apart from these advantages over the ferrous materials, these significant losses strength with increase in temperature and also these have a tendency for hot shortness and as compared to ferrous materials they shrink more. They are basically used for the following reasons:

1. Low Density
2. Attractive Colors
3. Softness and facility of cold working
4. Good formability
5. Corrosion resistance
6. Special Electrical and Magnetic properties
7. Good Castability

Aluminum Alloy Al-5083

This alloy comes in the category of wrought aluminum alloys. Normally, Aluminum alloy 5083 has 2.5% magnesium which is the major alloying element and 0.25% chromium. The designation to this type of alloy is comprised in the following manner, the first digit indicates the major alloying element which is magnesium here, and next digit describes the type of modification and the third and fourth place for other alloying elements. This alloy is basically popular due it properties like good workability, good mechanical strength, and very good corrosion resistance, especially in marine conditions. As it belongs to the group of aluminum alloys it bears the same properties as that of other aluminum alloys like low density and good thermal conductivity. This alloy is not heat treatable which means it can't be hardened by heat treatment, so it is hardened by cold work.

Mechanical Properties of Material

Characteristics of any material which describes the materials behavior under external loads are commonly referred as mechanical properties. As we know that all engineering components are likely to subject to external loads directly or indirectly, it is, therefore, necessary to have knowledge of the mechanical properties so as to avoid the chances of failures. These characteristics which are known as mechanical properties greatly rely on the structure of the material, especially about the microstructure arrangement. Commonly known mechanical properties are Strength, Hardness, Toughness, Resilience, Stiffness, Elasticity, Plasticity, Ductility, Malleability, etc.

LITERATURE REVIEW

Studies on the mechanical properties of Aluminum alloy Al 5083 have been made by various scholars in the past. The majority of these studies were focused on the mechanical properties of Aluminum alloy Al 5083 but very less studied its mechanical properties in the annealed condition.

Mhedhbiet. al. [1] performance of the homogenized AA1050 alloy, as well as after the different metallurgical conditions such as cold-rolling and cold-rolling annealed. For this reason, microstructures, microhardness, and tensile tests were studied. From the most important results, the optical micrographs show that with increasing cold-rolling reduction rate, the equiaxed grains are elongated along the rolling direction obviously. The accumulation of rolling reduction increases the work hardening effect, which is a good agreement with the improvement of strength and low plasticity. we can give some values; when the cold-rolling reduction is about 66 %, the ultimate tensile strength reaches 140 MPa, the microhardness is 53 HV0.3 but elongation is only 1.75 %. After cold-rolling and the annealing treatment, the SEM micrographs and the DRX patterns show more secondary phase precipitates and more intermetallic formed. With an increase of annealing temperature, the amount of precipitates increases and work hardening decrease, continuously. The elongation is improved to 36 % but the tensile strength is decreased to 86 MPa after the annealing at 350 °C for 1 hour.

Singh et al. [2] investigation for Mechanical properties of Aluminium Alloy Al 6061 Considering different Parameters of FSW. Two different type of tool shapes and shoulder surfaces for single weld configurations were used in experiments. It was shown that both tool types produce high-quality butt joints free from defects or imperfections as the visual inspection was done. The best tensile performance was obtained for FSW joints produced by a taper tool and the results obtained for joints produced by threaded tool shoulder are significantly lower. Tensile strength test indicated that welding speed is the main parameter which affects the tensile strength. Feed rate and tool shape are effecting second and third respectively. As the Impact toughness and Micro-hardness test are conducted, the Feed rate is the main factor, Welding speed, Tool shape are effecting respectively. As a result of the experiment the welding speed 600 RPM, Feed Rate 40 mm/min and Taper probe tool is the best optimum levels to get the maximum strength of mechanical properties. The differences between mechanical properties using different parameters were predicted based on a recently elaborated mathematical model developed for FSW joints.

Bhowmiket. al. [3] review on development of new technologies in the field of manufacturing, there is a strong need of new and advanced materials to be analyzed and studied so as to get the most of the benefits of new technologies. In lieu of this if we talk about nonferrous materials which have some unique properties as compared to ferrous materials. In nonferrous materials, a very promising material is aluminum alloy Al 5052 which have good corrosion resistance, especially in the marine atmosphere.

Shrivas& Kale [4] during his research aluminum alloys increases drastically in automobile and aerospace industries. The aluminum alloy takes the advantage of „strength to weight ratio‟ and corrosion properties over another structural element such as steel and its alloys. The altered mechanical properties are achieved in aluminum alloy by using different strengthening techniques such as age hardening etc. The favorable mechanical properties are explained by revealing the microstructure of corresponding alloy and intermediate phase compounds during formation of the corresponding alloy. Hence the study of microstructure and their impact on mechanical properties is essential. In the present review paper, the microstructure of aluminum alloys series are explained and their emphasis on the mechanical properties are discussed. By doing so, the research gap and the flow of research fields are exposed for further development.

Patnaik et al. [5] during their study on the effect of Al-5Ti-1B grain refiner on the microstructure, mechanical properties and acoustic emission characteristics of Al 5083 aluminum alloy, find out properties like hardness, impact toughness and tensile properties of unaltered Al 5083 alloy as per ASTM Standards and it was reported that the addition of Al–5Ti–1B grain refiner into the alloy caused a significant improvement in ultimate tensile strength and elongation values. The main mechanisms behind this improvement were found to be due to the grain refinement during solidification and segregation of Ti at primary alpha grain boundaries. Microstructural analysis showed the presence of primary α solid solution. No Al-Mg phase was found to be formed due to the presence of magnesium in the solid solution. The results indicated that the addition of Al–5Ti–1B grain refiner into the alloy caused a significant improvement in ultimate tensile strength (UTS).

Ertug & Kumruoglu [6] studied the corrosive behavior of 5083 and 1100 aluminum alloy in seawater under different conditions. During the investigation, the pit morphology on the polarized aluminum alloys showed hemispherical isolated deeper pits on the 5083 alloy. Samples of the 1100 alloy revealed a higher number of shallow pits (more close to patches of general dissolution). The results showed that the type of intermetallic particles in the aluminum alloy played a major role in passivity breakdown and pit morphology in seawater. It was reported that the corrosion resistance of 1100 alloy is better than 5083 in seawater both at room temperature and at 60 ºC. Also, it was found that with increasing the temperature the corrosion intensity also increases. In addition, low corrosion rate values evaluated using weight loss tests for both the alloys indicate their useful application in the marine atmosphere. Park et al [7] in their investigation of the mechanical behavior of 5000 and 6000 series aluminum alloy under cryogenic conditions. The material characteristics were investigated and summarized as a function of low temperature (110–293 K) and quasi-static strain rate (10^{-4} and 10^{-2} s^{-1}). It was found that with a decrease in temperature the strength and ductility was improved. It was also reported that these materials exhibit more ductility and also absorbs more energy to fracture at low temperatures. It was concluded that for large displacement involved structures 5000 series is more suited and for structures which are subjected to large loads 6000 series is more favorable. Nikolaevich el at [8] in their investigation for evaluating various advance materials for automobile bodies found that aluminum and its alloys due to the properties like light weight, high corrosion resistance and also because they can be recycled as compared to steel is most preferred in the manufacture of automobile bodies, especially 5xxx and 6xxx aluminum alloys. Maclins [9] in his investigation of aluminum alloy Al 6063 in sea water for tensile behavior found that, with corrosion and related damage there is a gradual decrease in mechanical properties. The investigation was carried out on 6063 aluminum alloy which was heat treated and soaked in seawater. It was found that corroded specimens were subjected to low impact damage. Also with the increase in the exposure time in the corrosive environment, there is a decrease in the ultimate tensile strength. And the chemical reaction increase with the time of exposure.

Akhil et al. [10] work on cooling characteristics of cast components with varying section size. In this study, aluminum alloy A356 is selected because it is widely used in automotive and aircraft industries in the form of components with varying section size. This study investigates how cooling rate and mechanical properties vary with varying section size. The experiment is performed that aluminum alloy ingot is heated in a muffle furnace and poured into the molds having mold cavity of varying dimensions. The cooling rate was measured using K type thermocouple during solidification of aluminum alloy. In order to investigate the effect of cooling rate on microstructure and mechanical properties microstructure analysis, impact test, tensile test, hardness test were performed. The results showed that mechanical properties of cast component of smaller section size are better. This is due to the fast cooling rate of smaller section cast component makes refining of the grain size of the aluminum alloy.

Ming et al. [11] studied on extruded 2024-T4 and 7075-T6 aluminum alloys are investigated by using an instrumented drop tower machine. The specimens are made from a 25 mm diameter extruded circular rod. The dynamic three-point bending tests of each alloy are carried out at different impact velocities. The initiation fracture toughness and average propagation fracture toughness of 2024-T4 and 7075-T6 are determined at different loading rates. The results show that both the initiation toughness and the propagation toughness increase with the loading rate. Further, the difference between the fracture toughness behaviors of 2024-T4 and 7075-T6 is found to be dependent on the variation of fracture mechanism. The comprehensive fractographic investigations of the fracture surfaces clearly demonstrate that the fracture mode of 2024-T4 is predominantly transgranular fracture with high-density small-sized dimples, and the fracture mode of 7075-T6 is a mainly intergranular fracture with many intermetallic particles in the bottom of voids located in the fracture surface.

Das et al [12] studied cry rolled Al 7075 of different thickness reductions (40% and 70%) for tensile and impact toughness behavior. In the study, it was reported that the tensile and impact toughness behavior shows an increment with cryorolling. During the investigation, microstructural characterization of the alloy was also carried out by using field emission scanning electron microscopy. In this, it was observed that after 70% thickness reduction grain structure is at ultrafine level. It was concluded that the improved tensile strength and impact toughness of the cry rolled Al alloy is due to grain refinement, grain fragments with high angle boundaries, and ultrafine grain formation by multiple cryorolling passes. In addition scanning electron microscopy analysis of the fracture surfaces of impact testing carried out on the samples in the temperature range of 200°C to 100°C. It was reported that with the combined effect of short annealing and aging, improved the strength and ductility of cry rolled samples, which is due to precipitation hardening and subgrain coarsening mechanism respectively. On the other hand, the impact strength of the cry rolled Al alloy has decreased due to high strain rate involved during impact loading.

Wang et al [13] investigated friction and wear properties of cold-rolled 5083 aluminum alloy of the thickness of 6 mm to 3 mm annealed at a different temperature. In the investigation, it was stated that 5083 aluminum alloy annealed at different temperatures almost have the same coefficient of friction under the same experimental condition, but the coefficient friction of the same sample will increase while temperature rises. During the investigation, it was observed that at the annealing temperature, Al-Mg alloys have grain boundary and surface magnesium segregation and their strength are also impossibly enhanced by heat treatment. X-ray diffract analysis (XRD) indicated that metallurgical phase has no obvious transformation with different annealing temperature. It was reported that the higher oxide layer of the surface, the smaller wear can be got. Also, it was stated that with the rise in the annealing temperature, the hardness decreases.

Kciuk el at [14] in their study on corrosion behavior of aluminum AlMg2.5, AlMg5Mn, and AlZn5Mg1 alloys and found that the corrosion resistance of AlZn5Mg in chloride solution is highest in comparison to another two aluminum alloys. In the investigation the corrosion resistance tests were done with the help of potentiodynamic method, registering anodic polarization curves in 3.5% NaCl solution at room temperature. And registering anodic polarization curves was conducted at the potential rate equal to 1mV/s. As the reference electrode was used saturated calomel electrode (SCE) and the auxiliary electrode was a platinum electrode. Vickers hardness test was done for determining mechanical properties The test was realized with the use of Hauser hardness tester. The observation of the surface morphology after corrosive tests was done using Digital Scanning Electron Microscope DSM 940 OPTION. It was observed for the corresponding test conducted during the investigation that the highest corrosion resistance in 3.5% NaCl solution was observed for AlZn5Mg1 aluminum alloy. And it was also observed that with an increase in Mg the corrosion resistance decreases in chloride solution.

Nik et al [15] studied the corrosion aspect of seawater for various aluminum alloys. The experiment was done at room temperature and in the atmosphere of seawater, where different types of aluminum alloys were subjected to aqueous corrosion in a salt spray chamber and normal seawater container. Starch which is considered to be natural corrosion inhibitor was used. To study the corrosion behavior of the alloy in seawater the electrochemical behavior was studied with various inhibitor concentration using electrochemical potentiodynamic reactivation (EPR), potentiodynamic polarization and electrochemical spectroscopy. It was reported that with the use of NaBz as an inhibitor the corrosive tendency of 6063 alloys in seawater is reduced appreciably. In addition to this with the help of scanning electron microscope, morphology tests were done in order to study the development of thin film on the samples.

Ramesh et al. [16] present work were to evaluate the stress corrosion cracking (SCC) behavior of the annealed Al-7075 alloy before and after Equal Channel Angular Pressing (ECAP). The SCC behavior of the Al-7075 alloy before and after ECAP was evaluated using slow strain rate testing (SSRT). Tensile and SCC behavior of the UNECAPed and ECAPed samples were compared. The elongation and ultimate tensile strength (UTS) was decreases 1.25, 1.1 times respectively after SCC in the annealed Al 7075. After ECAP, about 1.6 times decreases in elongation and 1.09 times decrease in UTS is observed. The decrease in ductility is more as compared to UTS. The fracture surface analysis (from the SSRT tests in 3.5% NaCl solution) revealed predominant ductile failure in the before ECAP and mixed (quasi-cleavage) mode of failure was observed after ECAP. Though the SCC resistance decreases due to ECAP, this appears a positive sign that the SCC may be improved by modifying process parameters and the condition of the sample.

Chee and Mohamad [17] presents an experimental study on precipitation of aluminum alloy 6061-T6 to determine the effect of artificial aging on the hardness of aluminum alloy 6061-T6. The precipitation hardening is a thermal treatment, which consists of a heat treatment, quenching, and artificial aging process. The experimental study is focused on artificial aging upon which the temperature is varying between 175 o C to 420 o C at different period of time. The Vickers hardness test is to evaluate the hardness of aluminum alloy 6061-T6 before and after aging process. The optimum aging time and the temperature is determined at the end of this experiment to obtain a reduction in energy and total cost. The study leads to the conclusion that the optimum aged was achieved between 175 o C to 195 o C with 2 to 6 hours of ageing time. The contribution of short time ageing is comparable to that of longer ageing time from previous studies. Mukhopadhyay et al. [18] studied on deformed up to 25% elongation in INSTRON at 788K. The grain boundary sliding due to this superplastic deformation was measured by Scanning Electron Microscope. The microstructure and texture development due to this deformation at elevated temperature was analyzed from the Orientation Image Microstructures i.e. the Electron Back Scattered Diffraction Image. The Orientation Image Microstructures revealed that superplastic deformation was associated with recovery and recrystallization in-situ process.

Gang et al [19] studied the microstructure and mechanical properties of 5052 Al alloy of thickness 8 mm processed by cryogenic rolling with reduction of thickness by 55% followed by 56% reduction by warm rolling. The properties were evaluated in each case. It was observed that if the material is treated by cryogenic rolling combined with warm rolling at 448K there is a significant increase in tensile strength up to 452 MPa. This increase in strength was due to the fine precipitate formation by warm rolling. For enhancing mechanical properties it was suggested to use cryogenic rolling combined with warm rolling. Paik [20] investigated the mechanical properties of two different aluminum alloys 5083 and 5383 under different welding conditions. Mechanical properties of fusion welded aluminum alloys are tested and compared with those of friction stir welded alloys. And it was reported that there is a reduction in mechanical properties with welding. Also, the tensile strength of friction stir welding is more in comparison to fusion welding. In order to carry out the investigation, tensile testing is undertaken on dog-bone type test specimen for aluminum alloys 5083 and 5383. It was also observed that the reduction in property is more significant in 5083 in comparison to 5383 alloys.

Nowotnik et al [21] investigate the effect of heat treatment parameters which are temperature and time on the tensile properties and fracture toughness of 6082 aluminum alloy. The uniaxial tensile test was conducted at room temperature to determine tensile strength, yield strength, and elongation of the 6082 aluminum alloy. Also, tension test was conducted on the aged alloy to determine the fracture toughness of the aluminum alloy 6082. Therefore, according to ASTM standard tests were performed on fatigue pre-cracked compact tension and sharp-notched specimens in both the longitudinal and transverse orientation with respect to the rolling direction. In the study, it was reported that the microstructure, mechanical properties and fracture toughness changes during artificial aging due to the precipitation strengthening process. Ozturk et al [22] studied the tensile properties of 5052 type aluminum-manganese alloy of 1.6 mm thickness in warm temperatures. He analyzed the uniaxial tensile deformation behavior of this aluminum magnesium alloy between room to 300°C and in the strain rate range of 0.0083-0.16 s^{-1}. He reported that the uniaxial tensile elongation of the material increases with increasing temperatures and decreases with increasing strain rates. Also, it was reported that the formability of this material at warm temperatures is better than the room temperature and concluded that the most suitable forming conditions were at 300°C and 0.0083 s^{-1}. With his findings, it was said that strain rate sensitivity plays an important role in the formability of this material at warm temperatures.

Overview

With industrial growth and globalization more and more advancements have been witnessed in the scientific area especially into R & D for providing new technology and materials so as to make improvements in the existing technology and things.

Every day and new and advanced materials are introducing with more and more utility. Some of the materials are artificial developed and others are customized according to specific requirements. If we talk about consumer electronics like for smaller, thinner components as well as for larger products, such as laptop computers, mobile devices, and televisions. And also fuel pipelines, tubes, heat exchangers, pressure vessels, home appliances like freezers, kitchen cabinets, etc.

In short, if we say about general sheet metal work we need materials which have good corrosion resistance, especially to salt water, lightweight, and high strength. Aluminum alloy Al 5083 due to its properties is well suited for use in above-said areas and especially in shipbuilding and marine application. And the important properties which make Aluminum alloy Al 5083 best is its mechanical properties and if these properties can be improved or well investigated will help to identify its actual potential so that they can be better utilized.

Also in recent past Aluminum alloy Al 5083 showed its presence more rapidly and there's an urgent need for enhancement and investigation of its mechanical properties. Attempts have been made by various scholars in this area. The present study is focused on how the mechanical properties such as strength, ductility, toughness, and hardness behave or change when Aluminum alloy Al 5083 is annealed to different temperatures. This not only helps to study the behavior of the material but also makes it more effective in utilization in various sectors.

Conclusions

The following conclusion can be drawn from the present investigation on mechanical properties of annealed aluminum alloy Al 5083. The following Gaps are found:

- There is a strong influence of annealing on the mechanical properties of aluminum alloy Al 5083.
- The annealing process decreases the tensile strength, hardness, and toughness of the material
- The annealing process improves the ductility or percentage elongation. The ductility goes on increasing with the increase of annealing temperature.
- With the increase in annealing temperature, there is a decrease in hardness, tensile strength and in toughness.
- Aluminum alloy Al 5083 shows an increase in ductility with an increase in annealing temperature which is a strong requirement in metalworking or fabrication but as there is a decrease in other mechanical properties with increase in annealing temperature the choice of selecting the best annealing temperature rest on the design consideration.

References

1. Mhedhbi M., Khlif M., Bradai C., (2017), Investigations of microstructural and mechanical properties evolution of AA1050 alloy sheets deformed by the cold-rolling process and heat treatment annealing, Journal of Materials and Environmental Sciences, JMES, 8(8), pp. 2967-2974, ISSN: 2028-2508.
2. Singh H., Verma M., SidhuH. S., Singh D., (2016), Experimental Investigation for Mechanical Properties of Aluminium Alloy Al 6061 Considering Different Parameters of FSW, International Research Journal of Engineering and Technology (IRJET), 3(2), pp. 635-641, ISSN: 2395 -0056.
3. Bhowmik A., Srivas S.P. and Khandelwal A.K.; A Review of the properties of Aluminum Alloy Al 5052, Journal of Scientific Research in Allied Science (ISSN: 2455-5800), Vol 2, No. 2 (2016): 25-30.
4. Shriwas A K., Kale V C., (2016), Impact of Aluminum Alloys and Microstructures on Engineering Properties – Review, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 3(13), pp. 16-22, ISSN: 2320-334X.
5. Amulya Bihari Pattnaik, S. D. (2015). Effect of Al–5Ti–1B grain refiner on the

microstructure, mechanical properties and acoustic emission characteristics of the Al5083 aluminum alloy. *Journal for Materials Research and Technology*, 171-179.

6. Ertug, B., & Kumruoglu, L. C. (2015). 5052 type Al-Mg and 6082 type Al-Mg-Si alloys for shipbuilding. *American Journal of Engineering Research*, 146-150.
7. Park, D.-H., Choi, S.-W., Kim, J.-H., & Lee, J.-M. (2015). The cryogenic mechanical behavior of 5000- and 6000-series aluminum alloys: Issues on application to offshore plants. *Cryogenics*, 44-58.
8. Nikolaevich, S. A., Valerievich, A. A., Igorevich, G. A., Alexandrovich, S. A., & Alexandrovich, S. M. (2014). Advanced materials of automobile bodies in volume production. *European Transport*, 1-27.
9. Maclins, P. (2014). Tensile Behavior of Aluminium Alloy 6063 - T6 In Sea Water. *International Journal of Engineering Research and Development*, 68-74.
10. K.T.Akhil, Sanjivi Arul, R.Sellamuthu, the effect of section size on cooling rate, microstructure and mechanical properties of A356 aluminum alloy in casting, process material science 5, 2014, pp 362-368
11. Ming-zhiXING, Yong-gang WANG, Zhao-xui JIANG, dynamic fracture behaviors of selected aluminum alloys under three-point bending, defense technology 9, 2013, pp.193-200
12. Das, P., Jayaganthan, R., & Singh, I. (2011). The tensile and impact-toughness behavior of cry rolled Al 7075 alloy. *Materials and Design*, 1298–1305.
13. Wang, L., Strangwood, M., Balint, D., Lin, J., & Dean, T. (2011). Formability and failure mechanisms of AA2024 under hot forming conditions. *Materials Science and Engineering*, 2648–2656.
14. Kciuk, M., Kurc, A., & Szewczenko, J. (2010). Structure and corrosion resistance of aluminum AlMg2.5; AlMg5Mn and AlZn5Mg1 alloys. *Journal of Achievements in Materials and Manufacturing Engineering*, 74-81.
15. Nik, W. B., Sulaiman, O., Fadhli, A., & Rosliza, R. (2010). Corrosion Behaviour of Aluminum alloy in seawater. *MARTEC* (pp. 175-180). Dhaka: The International Conference on Marine Technology.
16. Ramesh SK, Kondaiah G, Venkatachalam P and Ravisankar B. Stress corrosion cracking of Al 7075 alloy processed by equal channel angular pressing. International Journal of Engineering, Science, and Technology. 2010; 2(12):53-61.
17. Chee F T and Mohamad R S., (2009), Effect of hardness test on precipitation hardening aluminum alloy 6061-T6. Chiang Mai Journal of Science, 36(3):276-86.
18. Mukhopadhyay P., S. Biswas, and H. A. Chokshi, “Deformation characterization of superplastic AA7475 alloy,” Transactions of the Indian Institute of Metals, vol. 62, no. 2, pp. 149– 152, 2009.
19. Gang U. G., S. H. (2009). The Evolution of Microstructure and Mechanical Properties of a 5052 Aluminium Alloy by the Application of Cryogenic Rolling and Warm Rolling. Materials Transactions, 82-86.
20. Paik, J. K. (2009). Mechanical Properties of Friction Stir Welded Aluminum Alloys 5083 and 5383. International Journal of Naval Architecture and Ocean Engineering, 39-49.
21. Nowotnik, J. S., (2009). Effect of heat treatment on tensile and fracture toughness properties of 6082 alloy. Journal of Achievements in Materials and Manufacturing Engineering, 162-170.
22. Ozturk, S. T., (2008). Evaluation of tensile properties of 5052 type aluminum-magnesium alloy at warm temperatures. World Academy of Materials and Manufacturing Engineering, 95-98.