INTERNATIONAL JOURNAL of ENGINEERING SCIENCE AND APPLICATION
D. D. Olodu and A. Ogbemudia, Vol.4, No.3, September 2020

Analysis Of The Effects Of Process Parameters On The Mechanical Properties Of Developed Unalloyed Aluminium Sheets

Dickson Davıd Olodu*‡, Aibangbee Ogbemudia*

*Department of Mechanical Engineering, Faculty of Engineering, Benson Idahosa University, PMB 1100, Benin City, Edo State, Nigeria

(dolodu@biu.edu.ng, oaibangbee@biu.edu.ng)

‡ Corresponding Author; Dickson Davıd Olodu, Department of Mechanical Engineering, Faculty of Engineering, Benson Idahosa University, PMB 1100, Benin City, Edo State, Nigeria, dolodu@biu.edu.ng

Received: 30.08.2020 Accepted:24.09.2020

Abstract- Improper investigation of process parameters such as temperature and pressure in the production of Aluminium sheets had resulted to unpredictability in the mechanical properties of the developed Aluminium sheets in Aluminium manufacturing companies. This study analyses the effects of process parameters on the mechanical properties of the developed unalloyed Aluminium sheet in Aluminium manufacturing industries. The process parameters investigated in this study were pressure and temperature, these process parameters poses great challenges on the mechanical properties of the produced unalloyed Aluminium sheets, this process parameter when not properly controlled results to catastrophic failure on the unalloyed Aluminium sheets after production. The mechanical properties studied in this research were tensile strength, hardness, Young Modulus of Elasticity and Shear modulus respectively. These properties were determined at various production temperatures and pressures which ranged from 660°C to 2400°C and 20GPa to 78GPa respectively. From the evaluation, the obtained values for optimal tensile strength, young modulus of elasticity, shear modulus and Brinell Hardness Number were 621MPa, 69GPa, 25.5GPa, and 61 at temperature of 1921°C, 1610°C, 1442°C and 1800°C respectively. In comparison with pressure, the obtained values for optimal tensile strength, young modulus of elasticity, shear modulus and Brinell Hardness Number were 562MPa, 68GPa, 26.2GPa and 61 at pressure of 72GPa, 69.5GPa, 69.5GPa and 69.5GPa respectively. The coefficient of determination R^2 for the regression line equations for tensile strength, hardness, Young Modulus of Elasticity and Shear modulus ranged from 0.7254 (72.54%) to 0.9163 (91.63%), these results shows good adequacy of the experimental results obtained. The results obtained also shows that temperature and pressure have great effect on the mechanical properties of the developed unalloyed Aluminium sheet produced in Aluminium manufacturing industries.

Keywords Aluminium, Aluminium Manufacturing industries, Mechanical properties, Optimal, Process Parameters.

Özet- Alüminyum levha üretiminde sıcaklık ve basınç gibi proses parametrelerinin yanlış araştırılması, Alüminyum imalat şirketlerinde geliştirilen Alüminyum levhaların mekanik özelliklerinde öngörülemezliğe neden olmuştur. Bu çalışma, proses parametrelerinin Alüminyum imalat endüstrilerinde geliştirilen alaşımsız alüminyum levhanın mekanik özellikleri üzerindeki etkilerini analiz etmektedir. Bu çalışmada incelenen proses parametreleri basınç ve sıcaklıktı, bu proses parametreleri, üretilen alaşımsız Alüminyum levhaların mekanik özellikleri üzerinde büyük zorluklar yaratır, bu işlem parametresi, uygun şekilde kontrol edilmediğinde, alaşımsız Alüminyum levhalarda üretim sonrası feci arızaya neden olur. Bu araştırmada incelenen mekanik özellikler sırasıyla çekme mukavemeti, sertlik, Genç Elastisite Modülü ve Kayma modülüdür. Bu özellikler, sırasıyla 660oC ile 2400oC ve 20GPa ile 78GPa arasında değişen çeşitli üretim sıcaklıkları ve basınçlarında belirlenmiştir. Değerlendirmeden elde edilen değerler sırasıyla 1921oC, 1610oC, 1442oC ve 1800oC sıcaklıklarda optimum gerilme mukavemeti, genç elastisite modülü, kesme modülü ve Brinell Sertlik Numarası için 621MPa, 69GPa, 25.5GPa ve 61'dir. Basınçla karşılaştırıldığında optimum gerilme mukavemeti, genç elastisite modülü, kesme modülü ve Brinell Sertlik Numarası için elde edilen değerler 72GPa, 69.5GPa, 69.5GPa ve 69.5GPa basınçta sırasıyla 562MPa, 68GPa, 26.2GPa ve 61'dir. Gerilme mukavemeti, sertlik, Young Modülü ve Kesme modülü için regresyon çizgisi denklemleri için R2 belirleme katsayısı 0,7254 (% 72,54) ile 0,9163 (% 91,63) arasında değişmiştir, bu sonuçlar elde edilen deneysel sonuçların iyi yeterliliğini göstermektedir. Elde edilen sonuçlar ayrıca, Alüminyum imalat sanayinde üretilen gelişmiş alaşımsız alüminyum levhanın mekanik özellikleri üzerinde sıcaklık ve basıncın büyük etkisi olduğunu göstermektedir.

Anahtar Kelimeler -Alüminyum, Alüminyum İmalat endüstrileri, Mekanik özellikler, Optimal, Proses Parametreleri..

1. Introduction

Inadequate investigation of process parameters such as temperature and pressure on the mechanical properties of produced Aluminium sheet have resulted to inconsistency in its mechanical properties, hence, this results to the failure of Aluminium sheet used in Engineering construction. Aluminum is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor such as copper [1]. This has made aluminum the first choice for major power transmission lines [2]. It is also a superb heat sink for many applications that require heat to be drained away rapidly, such as in computer motherboards and LED lights. Aluminum naturally generates a protective thin oxide coating which keeps the metal from making further contact with the environment [3]. It is particularly useful for applications where it is exposed to corroding agents, as in roofing of buildings and in vehicles. In general, aluminum alloys are less corrosion-resistant than pure aluminium (Unalloyed Aluminium), except for marine magnesium-aluminum alloys.

Kok [4] studied the mechanical properties of Al_2O_3 particle reinforced 2024 Al alloy composites produced through vortex method. It was reported that optimum conditions of the production process were 700 °C (pouring temperature), 550 °C (preheated mold temperature), 900 rev/min (stirring speed), 5 g/min (particle addition rate), 1 min (stirring time) and 6 MPa (applied pressure). Kumar et al., [5] reported that the hardness and tensile strength of A359/Al_2O_3 MMC has been increased. It was also observed that electromagnetic stirring action adopted during the fabrication resulted in smaller grain size and good particulate matrix interface bonding. A successful attempt has been made by Venkatesh and Harish [6] on Al/SiC composites produced through the powder metallurgy route to achieve the desired properties and also to improve the mechanical properties. For a variety of reinforcements, improvement in strength, fatigue, modulus, wear resistance and creep has been demonstrated by Neih and Chellman; Friend [7, 8]. Studies on trimodal Aluminium metal matrix composites and the factors affecting their strength were reported by Yao et al., [9], of these factors, tensile strength was the most convenient and widely quoted measurement which is of central importance in many applications. Saravanan et al., [10] observed that there is an increase of 30% in hardness and an increase in tensile strength that is almost twice that of base aluminum alloy for TiB_2 particulate reinforced composites. The influence of stirring speed and stirring time on the distribution of particles in SiC AMC has been analyzed by Prabu et al.,[11]. Nieh et al., [12] also observed that in the early stages of processing a non-uniform distribution of reinforcement, which persists to the final product in the forms of steaks or clusters of reinforcement with their attendant porosity all of which lowered the strength, ductility, and toughness of the Aluminium material. Furthermore, for a given matrix alloy, the elongation to failure is reduced by increasing volume fraction [13]. Rozovsky et al., [14] reported that the compression of a short cylinder between anvils is a much better test for metal working applications. The deformation behavior of solid cylinders of an aluminum alloy metal matrix composite under dry condition was estimated by Joardar et al., [15]. Orbulov and Ginsztler [16] observed that engineering factors such as the aspect ratio (height/diameter ratio) of the specimens and the temperature of the tests, have significant effect on the compressive strength and properties of Aluminium. The effect of reinforcing particle shape and interface strength on the deformation and fracture behavior of an Al/Al_2O_3 composite was investigated by Romanova et al., [17], they observed that interface debonding and particle cracking were the two mechanisms for a particle fracture. In a study by Kumar and Kumar [5], a series of Al6061 aluminium matrix composites with 5, 10 and 15 weight percentage of TiB_2 particles were manufactured through the powder metallurgy route followed by hot extrusion. No evidence of reaction products was observed in samples heated up to 500ºC during heat treatment. Second intermetallic phases of Ti_3 (Al, Si) were found at the reinforcement / matrix interfaces. A major improvement of mechanical behavior was observed in composites reinforced with 10% TiB2 due to a better distribution of reinforced phase in the matrix. It was noted that at high temperatures (300ºC) the presence of reinforcement particles resulted in very low tensile strength i.e., as low as 120 MPa with presence of 5% particulate. Feng & Froyen [19] studied the influences of processing parameters on the kinetics of TiB_2 formation as well as on the microstructure of the composite products. Strings as well as clusters of particulate agglomerates were identified to be the distinct microstructural features of the composites manufactured. Commercial pure Al blocks (99.5%) were used by them as base metal and K_2TiF_6 and KBF_4 as the salt powders.

This research focused on the analysis of the effects of process parameters on the mechanical properties of developed unalloyed aluminium sheets.

2. Materials And Methods

The materials used in this study is unalloyed Aluminium sheet obtained from Differential Aluminium Company located in Benin City, Edo State, Nigeria. These materials were subjected to various temperatures and pressures ranging from 670ºC to 2400ºC and from 20Gpa to 78 GPa respectively. These materials produced at various temperatures and pressures were evaluated for mechanical properties after cooling.

2.1 Production of Unalloyed Aluminium Sheets

In the production of unalloyed aluminum sheets, the sheet ingots or slabs were first smoothened in order for the Aluminium ingots to shine like mirror. The smoothened materials were rolled into thin sheet metal through a rolling machine after being subjected to various temperatures and pressures ranging from 670ºC to 2400ºC and from 20GPa to 78 GPa respectively. This process is called hot rolling. The sheets produced were rolled into coils in preparation for the next stage. The next stage for these **aluminum sheets** is cold rolling process. The produced sheets were flattened into different thickness to suit different applications of the users such as building and c. This is where these sheets are flattened into different thicknesses to suit the many applications these are to be used for and to suit the needs of construction work. Furthermore, the rolled Aluminium sheets undergo different finishing processes such as annealing and surface treatment depending on the type of Aluminium produced. Before these unalloyed Aluminium sheets were shipped out to the respective companies that ordered them, inspection were conducted to ensure that these aluminum sheets are of the right quality. Unalloyed Aluminum sheet is an essential material for several industries, most notably aerospace and automobile construction.

2.2 Testing of Unalloyed of Aluminium Sheets

Fourty eight (48) samples of the developed unalloyed Aluminium sheets were produced at various temperature and pressure, and were tested according to American Standard of Testing Machine (ASTM) using the tensometer and Charpy Impact Test machines respectively. Furthermore, twelve (12) samples each were used for each mechanical properties, the tensile strength of the unalloyed Aluminium sheets were also tested on a 10 ton DAK tensile testing machine at a constant cross head speed of 1 mm/min after the tensile specimens ASTM-E8M were prepared for testing. A total of twelve (12) samples were tested in each case and average values were obtained. The data obtained were further evaluated for mechanical properties for the developed Unalloyed Aluminium sheets.

2.3 Evaluation of Developed Unalloyed Aluminium Sheets for Mechanical Properties at Various temperatures and Pressures

The developed unalloyed Aluminium sheets samples were evaluated for mechanical strength (tensile strength, young modulus of elasticity, Brinell hardness and shear modulus) using Equation 1 to 4 respectively [18].

$$\text{Tensile strength} = \frac{\text{Maximum Load}}{\text{Original Cross - Sectional Area}} \quad (1)$$

$$\text{Young's modulus of Elasticity} = \frac{Stress}{Strain} = \frac{FL_o}{L_m - L_o} \quad (2)$$

Where F= applied force, l_o=original length; l_m=Final length

$$\text{shear modulus} = \frac{\text{shear stress}}{\text{shear strain}} = \frac{\frac{F}{A}}{\frac{x}{y}}. \quad (3)$$

Where F= applied force: A=Cross-sectional Area; x=extension; y-original length

$$\text{Brinell Hardness Number (BHN)} = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}} \quad (4)$$

Where P is the load in kilogram, D is the steel ball diameter in millimeter, and d is the depression diameter or indentation diameter.

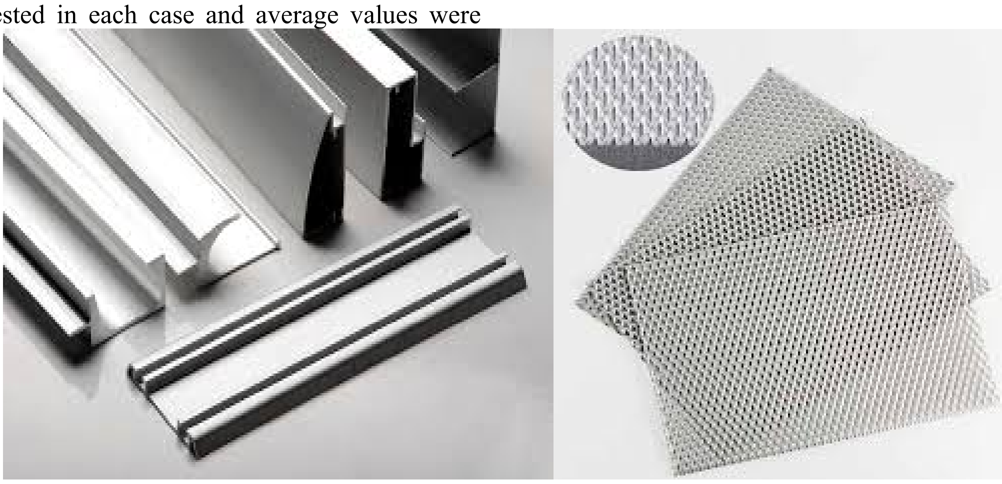

Fig. 1. Developed Aluminium Sheets

.

3. Results and Discussion

Figures 2, 4, 6, 8 shows the effects of temperature on the tensile strength, young modulus of elasticity, shear modulus and hardness of the developed unalloyed Aluminium sheets while Figures 3, 5, 7, 9 shows the effects of pressure on the tensile strength, young modulus of elasticity, shear modulus and hardness of developed unalloyed Aluminium sheets respectively.

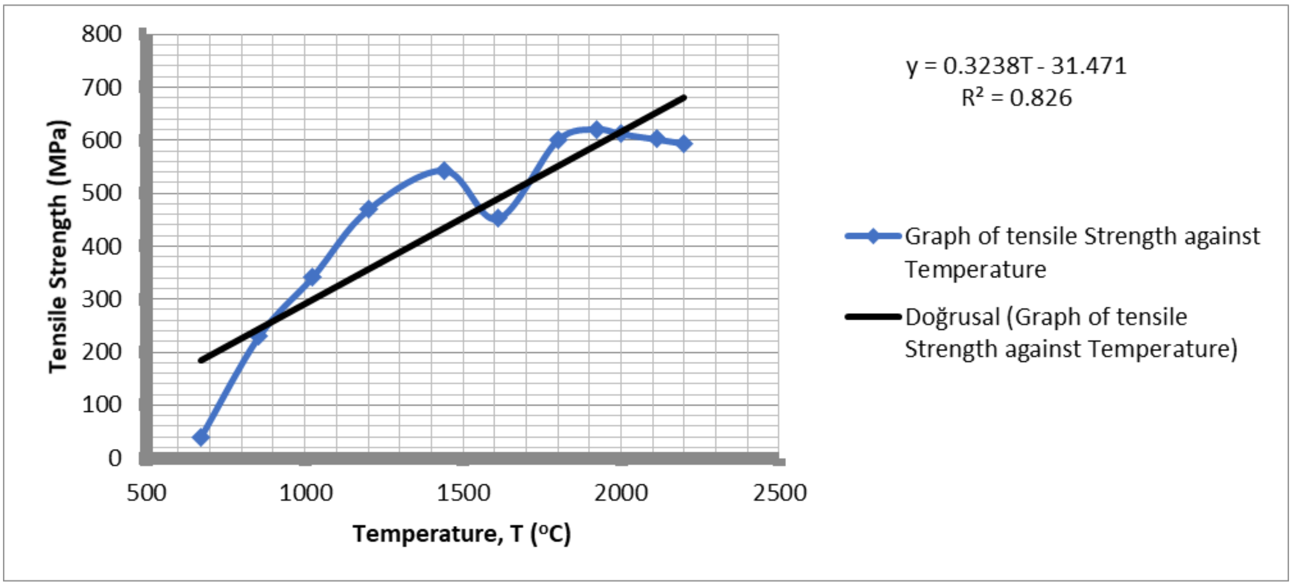

Fig. 2. Graph of the Effect of Temperature on the Tensile Strength of the Developed Aluminium Sheet

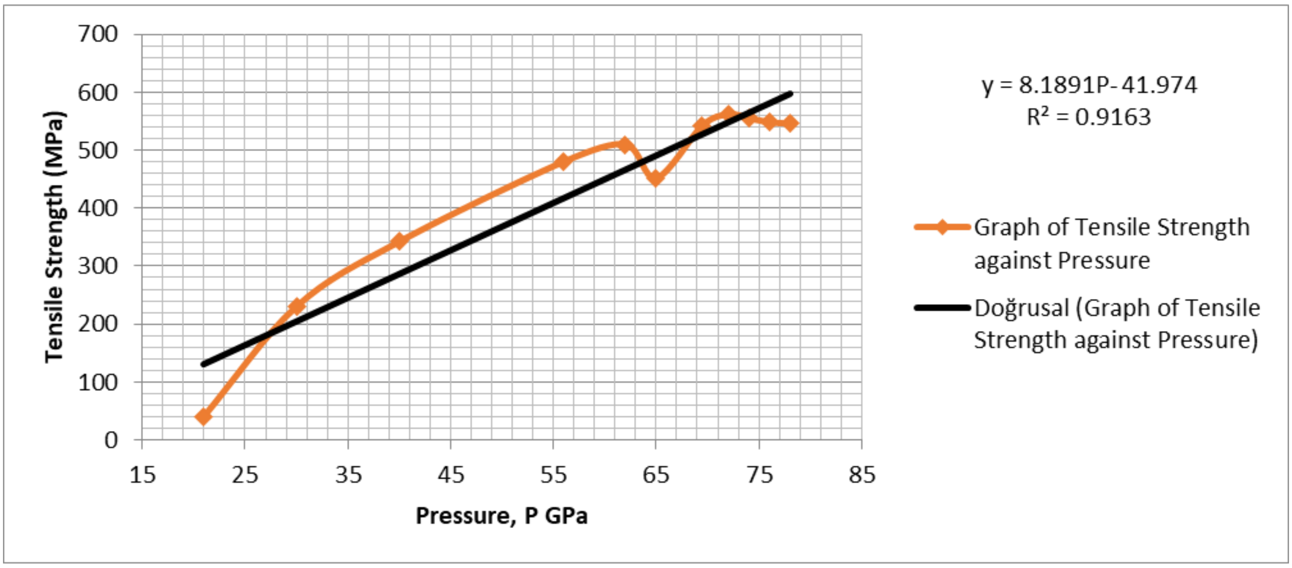

Fig. 3. Graph of the Effect of Pressure on the Tensile Strength of the Developed Aluminium Sheet

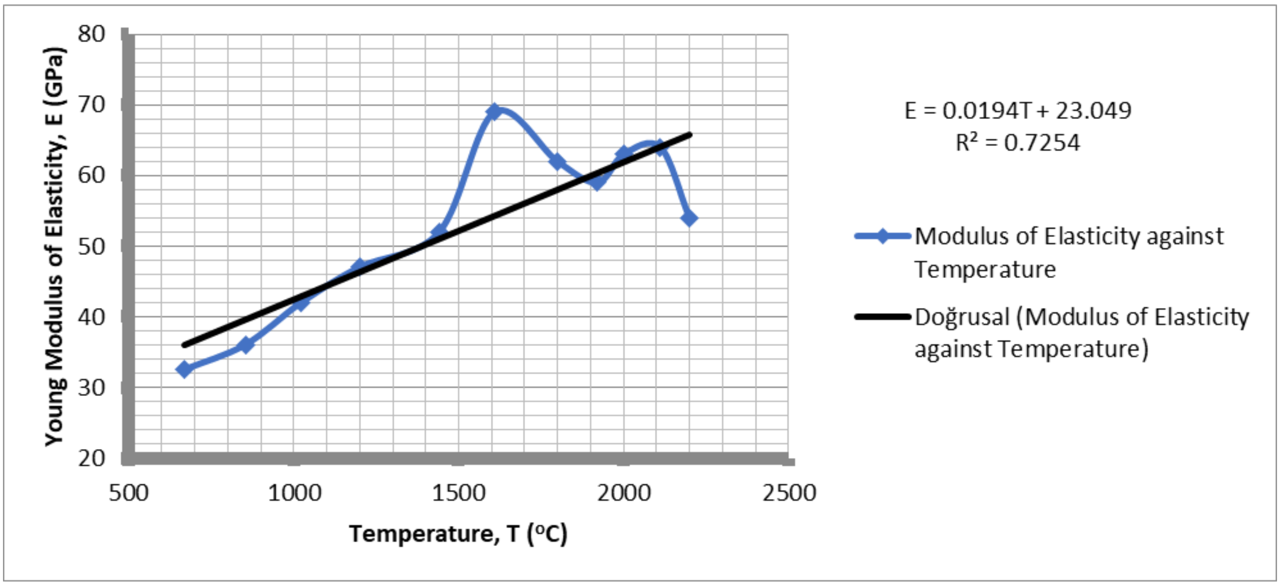

Fig. 4. Graph of the Effect of Temperature on the Modulus of Elasticity of the Developed Aluminium Sheet

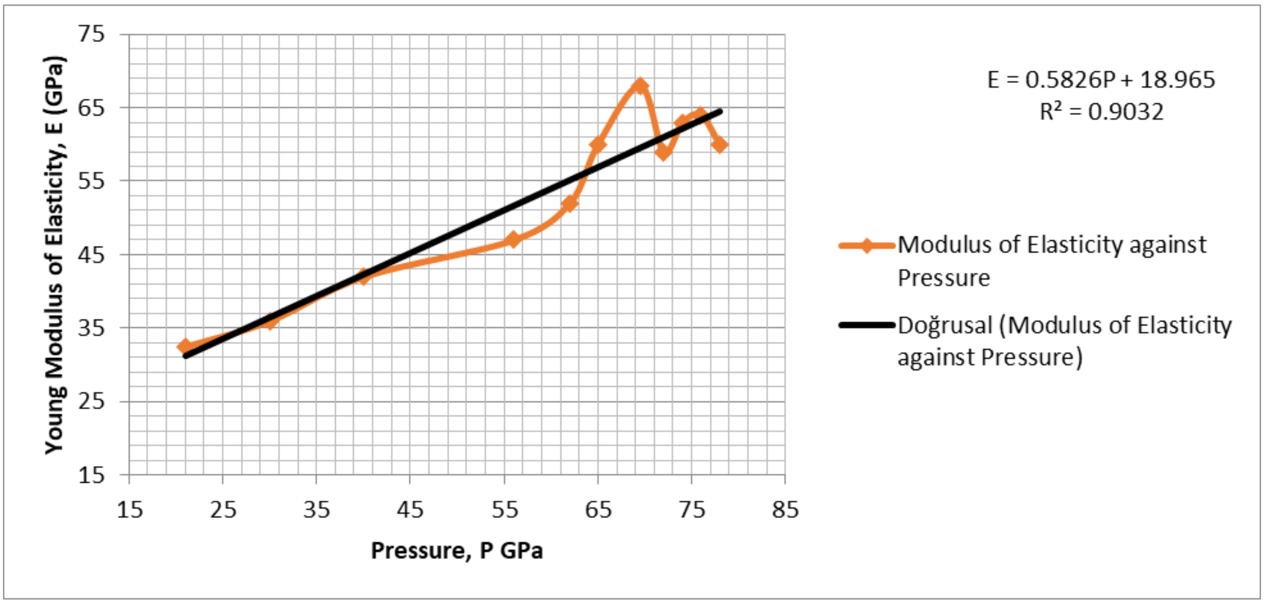

Fig. 5. Graph of the Effect of Pressure on the Modulus of Elasticity of the Developed Aluminium Sheet

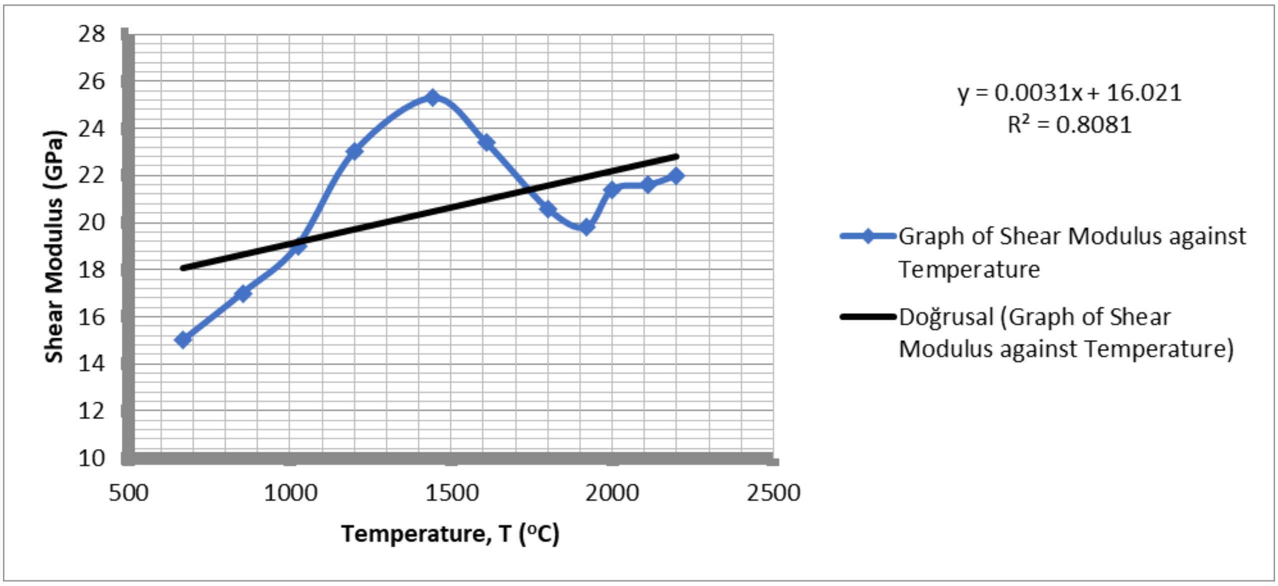

Fig. 6. Graph of the Effect of Temperature on the Shear Modulus of the Developed Aluminium Sheet

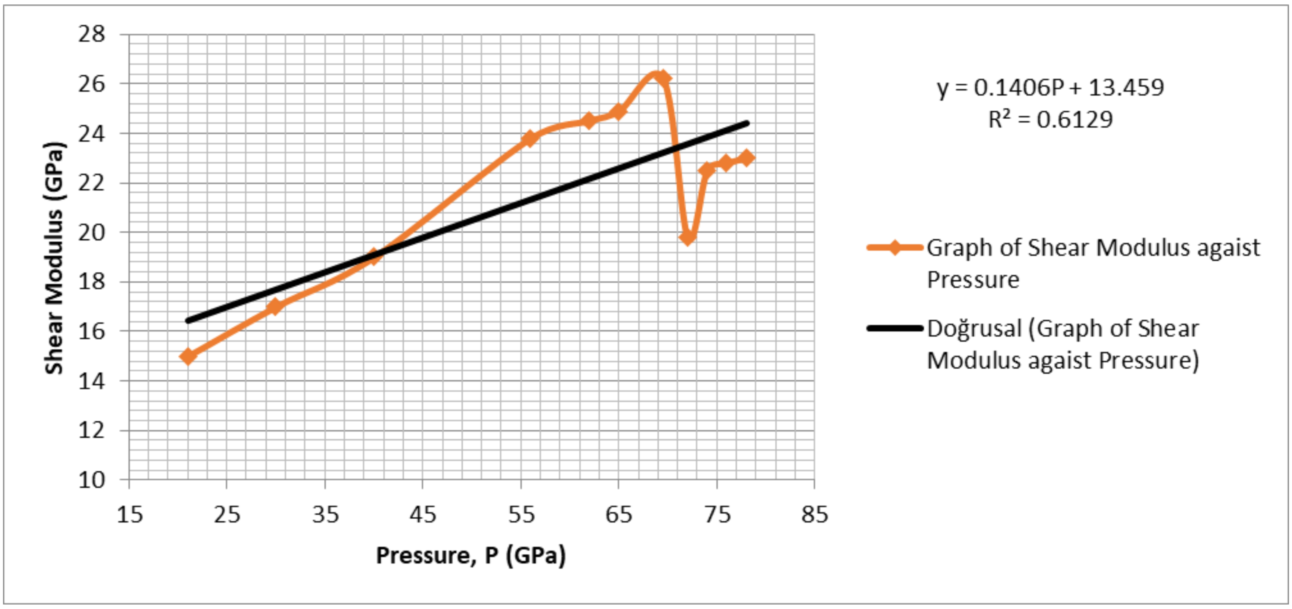

Fig. 7. Graph of the Effect of Pressure on the Shear Modulus of the Developed Aluminium Sheet

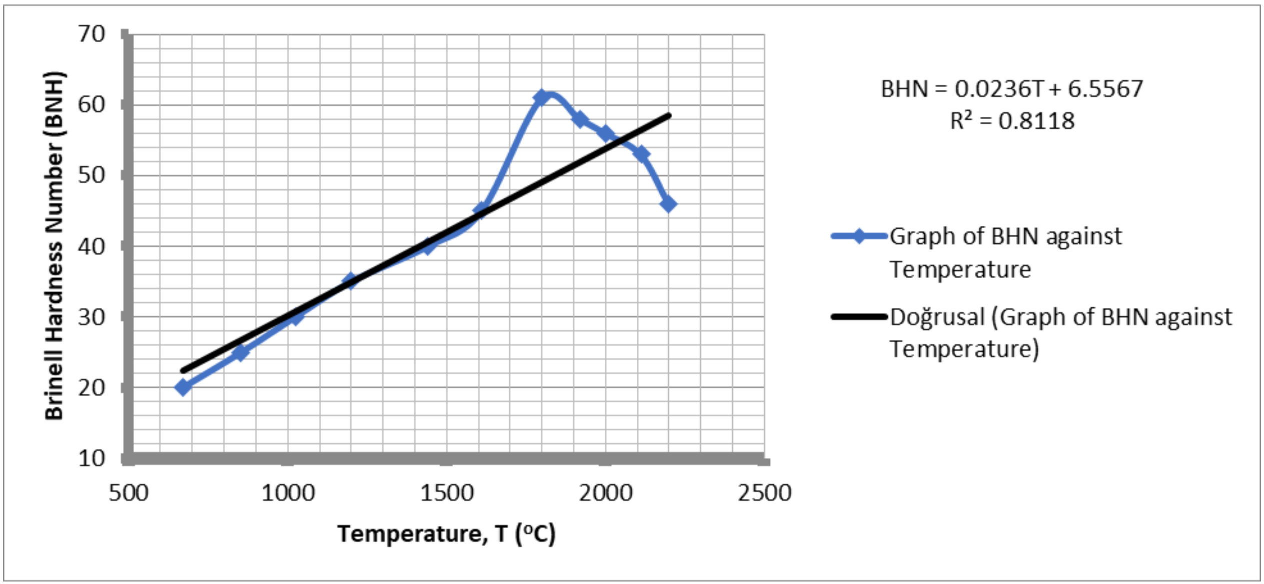

Fig. 8. Graph of the Effect of Temperature on the Brinell Hardness Number of the Developed Aluminium Sheet

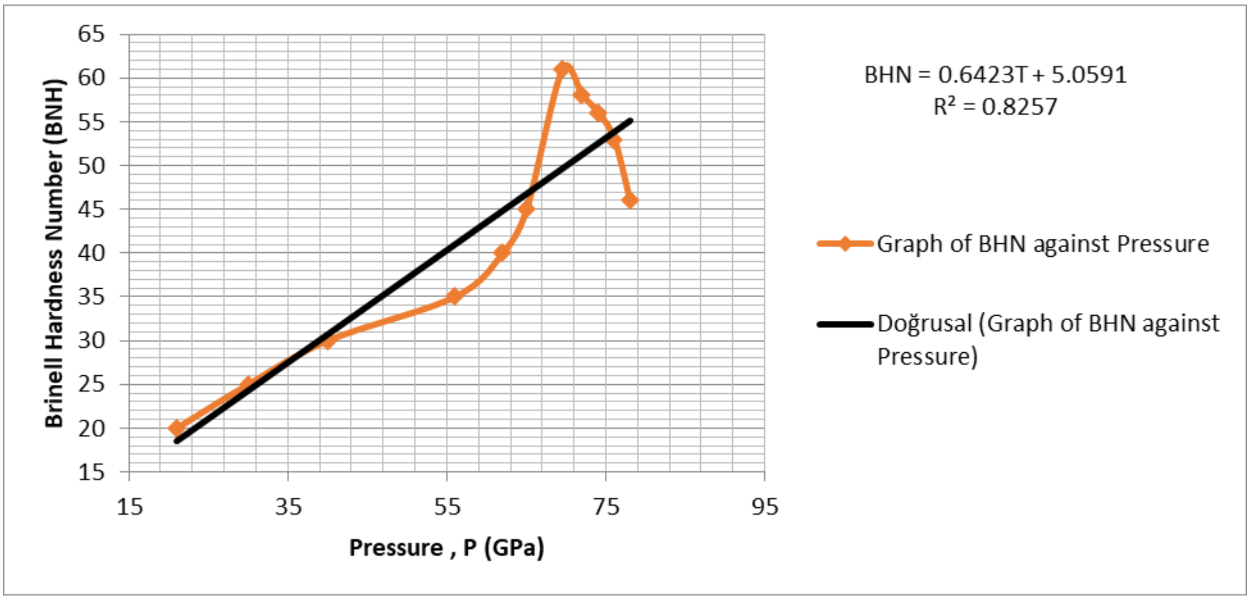

Fig. 9. Graph of the Effect of Pressure on the Brinell Hardness Number of the Developed Aluminium Sheet

3.1 Discussion of Results

3.1.1 Effect of Temperature and Pressure on the Tensile Strength of Developed Unalloyed Aluminium Sheet

In figure 2, as the temperature increases the tensile strength of Aluminium increases continuously upto a temperature of 1450°C after which the tensile strength decreases till temperature of 1500°C and finally increases to attain its optimal tensile strength of 621MPa at a temperature of 1921°C after which the tensile strength decreases as temperature increases furtherly. Similarly, in Figure 3, as the temperature increases the tensile strength of Aluminium also increases continuously upto a pressure of 66.5GPa after which the tensile strength decreases till pressure of 69.5GPa and finally increases to attain its optimal tensile strength of 562MPa at a pressure of 72GPa after which the tensile strength decreases as temperature increases furtherly. In addition, at higher temperatures, the internal energy of atoms is high, as a result, the atoms of the Aluminium material vibrate more vigorously with high thermal agitation. When these agitations are high the movement of dislocations (movement represent ductility of material) becomes easy. Hence, it requires a very less stress to tear the dislocations from their equilibrium positions. Therefore, Aluminium materials exhibit low yield and ultimate strengths at high temperatures. Furthermore, the coefficient of determination (R^2) for the regression line equations for tensile strength were 0.8260 and 0.9163 respectively, these results show good adequacy of the experimental results obtained. This result compared favourably with the result obtained by Kumar et al., [5] with coefficient of determination R^2 of 0.82 for A359/Al_2O_3 metal matrix composite using electromagnetic stir casting method, the difference in values obtained is due to different materials and parameters considered in the experiments. The results obtained from this study also shows that temperature and pressure contributes significantly in the production of Aluminium sheets and have great effect on the mechanical property (tensile strength) of the developed Aluminium sheets produced in Aluminium manufacturing industries.

3.1.2 Effect of Temperature and Pressure on the Young Modulus of Elasticity of Developed Unalloyed Aluminium Sheet

In figure 4, as the temperature increases the Young modulus of elasticity of Aluminium increases continuously till it attained its optimal Young modulus of elasticity of 69GPa at a temperature of 1610°C after which the Young modulus of elasticity decreases as temperature increases furtherly. This was due to molecular break down or degradation in the Aluminium matrix. Similarly, in Figure 5, as the temperature increases the Young modulus of elasticity of Aluminium increases continuously till it attain an optimal Young modulus of elasticity of 68GPa at a pressure of 69.5GPa after which the Young modulus of elasticity decreases as temperature increases furtherly. In addition, at higher pressure, the internal energy of atoms is high, as a result, the atoms of the material vibrate more vigorously with high agitation caused by high pressure. When these agitations are high the movement of dislocations (movement represent ductility of material) becomes easy. Hence, it requires a very less stress to tear the dislocations from their equilibrium positions. Therefore, Aluminium materials exhibit low yield and ultimate strengths at high temperatures and pressures. Furthermore, the coefficient of determination (R^2) for the regression line equations for Young modulus of elasticity were 0.7254 and 0.9032 respectively, these results show good adequacy of the experimental results obtained. The results in this study compared favourably with the result obtained by Kumar et al., [5] with coefficient of determination (R^2) of 0.82 for A359/Al_2O_3 metal matrix composite using electromagnetic stir casting method. The results obtained also shows that temperature and pressure contributes significantly in the production of Aluminium sheets and have great effect on the mechanical properties (Young modulus of elasticity) of the developed Aluminium sheets produced in Aluminium manufacturing industries.

3.1.3 Effect of Temperature and Pressure on the Shear Modulus on Developed Aluminium Sheet

In figure 6, as the temperature increases the shear modulus of Aluminium increases continuously till it attained its optimal shear modulus of 25.3GPa at a temperature of 1442°C after which the shear modulus decreases as temperature increases furtherly. This was due to molecular break down or degradation in the Aluminium matrix. Similarly, in Figure 7, as the temperature increases the shear modulus of Aluminium increases continuously till it attain an optimal shear modulus of 26.2GPa at a pressure of 69.5GPa after which the shear modulus decreases as temperature increases. In addition, at higher pressure, the internal energy of atoms increases causing high dislocation in the unalloyed aluminium sheets. Therefore, Aluminium materials exhibit low yield and ultimate strengths at high temperatures and pressures. Furthermore, the coefficient of determination R^2 for the regression line equations for shear modulus were 0.8081 and 0.6129 respectively, these results show fairly good adequacy of the experimental results obtained. The results obtained in this study compared favourably with the result obtained by Kumar et al., [5] and Venkatesh and Harish [6] with coefficient of determination R^2 of 0.82 and 0.78 respectively for A359/Al_2O_3 metal matrix composite using electromagnetic stir casting method. The results obtained also shows that temperature and pressure contributes significantly in the production of Aluminium sheets and have great effect on the mechanical properties of the developed Aluminium sheets produced in Aluminium manufacturing industries.

3.1.4 Effect of Temperature and Pressure on the Brinell Hardness Number (BHN) of Developed Aluminium Sheet

In figure 8 and 9, as the temperature increases the Brinell Hardness Number (BHN) of Aluminium increases continuously till it attained its optimal Brinell Hardness Number of 61 at a temperature of 1800°C and pressure of

69.5 GPa respectively, after which the Brinell Hardness Number decreases as temperature increases furtherly. This was due to molecular break down or degradation in the Aluminium matrix. In addition, at higher pressure, the internal energy of Aluminium atoms becomes high, as a result, the atoms of the Aluminium material vibrate more vigorously with high agitation caused by high temperature and pressure. When these agitations becomes high the movement of dislocations becomes easy. Hence, it requires a very less stress to tear the dislocations from their equilibrium positions. Therefore, Aluminium materials exhibit low yield and ultimate strengths at high temperatures and pressures. Furthermore, the coefficient of determination (R^2) for the regression line equations for Brinell Hardness Number were 0.8118 and 0.8257 respectively, these results show fairly good adequacy of the experimental results obtained. This result compared favourably with the result obtained by Kumar et al., [5] with coefficient of determination R^2 of 0.82 for A359/Al_2O_3 metal matrix composite using electromagnetic stir casting method. The results obtained also shows that temperature and pressure contributes significantly in the production of Aluminium sheets and have great effect on the mechanical property (hardness) of the developed Aluminium sheets produced in Aluminium manufacturing industries.

4. Conclusion

The research on the analysis of the effects of process parameters on the mechanical properties of developed unalloyed Aluminium sheets had been achieved. The mechanical properties studied in this research were tensile strength, young modulus of elasticity, shear modulus and hardness respectively. From the analyses, the optimum mechanical properties of unalloyed Aluminium sheets depends on the process parameters such temperature and pressure. The coefficient of determination R2 obtained for the regression line equations for tensile strength, hardness, young modulus of elasticity and shear modulus ranges from 0.7254 to 0.9163, these results show good adequacy of the experimental results obtained. The results obtained also shows that temperature and pressure have great effect on the mechanical properties of the developed Aluminium sheets produced in Aluminium manufacturing industries. Furthermore, it can be concluded that process parameters such as temperature and pressure is the key to a successful production of Aluminium sheets with high mechanical strength and durability.

References

[1] Allain, S., Chateau, J. P., Bouaziz, O., and Guelton, S. N. Correlations between the Calculated Stacking Fault Energy and the Plasticity Mechanisms in Fe–Mn–C alloys. Matererial Science Engineering. A 387–389, 158–162, 2004. doi:10.1016/j.msea.2004.01.059

[2] Fu, L. M., Li, Z. M., Wang, H. N., Wang, W., and Shan, A. D. Lüders-like Deformation Induced by Delta-Ferrite-Assisted Martensitic Transformation in a Dual-Phase High-Manganese Steel. Scrience Material Journals. 67, 297–300, 2012. doi:10.1016/j.scriptamat.2012.05.010

[3] Bhaskar and Sharief, A. Effect of Solutionising and Ageing on Hardness of Al2024-beryl Particulate Composite. Journal of Mechanical Engineering and Technology (JMET), 4(1), 81-90, 2012.

[4] Kok M. Production and Mechanical Properties of Al2O3 Particle-Reinforced 2024 Aluminium Alloy Composites. Materials Processing Technology Journal, 161(3), 381-387, 2005.

[5] Kumar A, Lal S, Kumar S. Fabrication and Characterization of A359/Al2O3 Metal Matrix Composite using Electromagnetic Stir Casting Method. Journal of Materials Research and Technology. 2(3), 250-254, 2013.

[6] Venkatesh and Harish, 2015 Venkatesh B, Harish B. Mechanical Properties of Metal Matrix Composites (Al/SiCp) Particles Produced by Powder Metallurgy. International Journal of Engineering Research and General Science. 3(1), 1277-1284, 2015.

[7] Neih T.G, Chellman D.J. Modulus Measurements in Discontinuous Reinforced Aluminum Composites. Scripta Metallurgica. 18, 925-938, 1984.

[8] Friend C.M. The Effect of Matrix Properties on Reinforcement is Short Al2O3 Fiber-Al MMCs. Journal of Materials Science. 22(8), 3005-3010, 1987.

[9] Yao B, Hofmeister C, Patterson T, Sohn Y.H, Van Den Bergh M, D. Microstructural Features Influencing the Strength of Trimodal Aluminum Metal-matrix-Composites. Composites Part A: Applied Science and Manufacturing. 41(8), 933-941, 2010.

10] Saravanan C, Subramanian K, Ananda Krishnan V, Sankara Narayanan R. Effect of Particulate Reinforced Aluminium Metal Matrix Composite. Mechanics and Mechanical Engineering. 19(1), 23-30, 2015.

[11] Prabu S.B, Karunamoorthy L, Kathiresan S, Mohan B. Influence of Stirring Speed and Stirring Time on Distribution of Particles in Cast Metal Matrix Composite. Journal of Materials Processing Technology. 171(2), 268-73, 2006.

[12] Nieh T.G, Raninen R.A, Chellman D.J. Microstructure and Fracture in SiC Whisker Reinforced 2124 Aluminum Composite. Proceedings of the Fifth International Conference on Composite Materials. Metallurgical Society, Inc., 825-842, 1985.

[13] Crowe C.R, Gray R.A, Hasson D.F. Microstructure Controlled Fracture Toughness of SiC/Al Metal Matrix Composites. Proceedings of the Fifth International Conference on Composite Materials, 843-66, 1985.

[14] Rozovsky E, Hahn W.C, Avitzur B. The Behavior of Particles During Plastic Deformation of Metals. Metallurgical Transactions. 4(4), 927-30, 1973.

[15] Joardar H, Sutradhar G, Das N.S. FEM Simulation and Experimental Validation of Cold Forging Behavior of LM6 Base Metal Matrix Composites. Journal of Minerals and Materials Characterization and Engineering. 11(10), 989-994, 2012.

[16] Orbulov I.N, Ginsztler J. Compressive Behaviour of Metal Matrix Syntactic Foams. Acta Polytechnica Hungarica. 9(2), 43-56, 2012.

[17]Romanova V.A, Balokhonov R.R, Schmauder S. The Influence of the Reinforcing Particle Shape and Interface Strength on the Fracture Behavior of a Metal Matrix Composite. Acta Materialia. 57(1):97-107, 2009.

[18] Olodu D.D. and Osarenmwinda J.O. Investigation of Polypropylene-Grass Composite Using Split-Split Plot Experimental Design. Advances in Engineering Design Technology, 1(1), 40-48, 2019.

[19] Feng I. and Froyen E. Microstructures of in situ Al/TiB2 MMCs Prepared by a Casting Route. Journal of Materials Science. 35(4), 837-850, 2000.