ABUAD Journal of Engineering Research and Development (AJERD)
Volume 2, Issue 2, 32-42
ISSN: 2645-2685

Investigation of the Mechanical Properties of Squeeze Cast Aluminium Alloy (Al-Si Alloy)

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Date Submitted: 30/06/2019
Date Accepted: 26/08/2019
Date Published: 31/12/2019

Abstract: *Scrap aluminium alloy are littered everywhere because poor recycling outlets. These Al-alloy could recycled to other useful products such as household accessory. These scraps are collected from used aluminium components such as knocked engine blocks, shipping containers, etc. Products sand casting shown high percentage of different types of defects, therefore squeeze casting method was attempted. Scraped Al-alloys were collected and casted using squeeze casting method, and the mechanical properties and microstructures of the casts were determined by varying the cast conditions such as pouring temperature, pouring time and the applied pressure to the mould. The results obtained for tensile test, hardness test, impact shows that the specimen P3 (700 °C, 10 min and 20 Mpa) had improved properties of 214 MN/mm2, 77.06 BHN and 16.06 J respectively than that of sand cast Al-alloy.*

Keywords: *Squeeze casting, tensile testing, impact testing, microstructure, scrab, aluminium*

1. INTRODUCTION

Aluminium alloys are widely used in aerospace, automobile and electronic industries due to their favourable properties such as low density, low weight, low cost of production and good mechanical properties (such as tensile strength, hardness impact strength e.t.c.), better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of aluminium alloy and relatively low cost of production make the Al-alloy a very attractive alternative for a variety of applications considering strength to weight ratio, corrosion resistance viewpoints, (Brown, Barnes, Bigelow, & Dodd, 2009).

According to (Su, Oon, Bai, & Jarfors, 2010) Metal casting is any process of melting metal and pouring it into mould in order to produce the required shapes. The properties of the resulting shapes (components) are of topmost important. If die casting is to be cost effective and produce intricately shaped components, then defects such as porosity and shrinkage after solidification which lower mechanical performance must be avoided. Dhanashekar, (2014) Squeeze casting is the combination of the casting and forging processes that can be done with help of high pressure when it is applied during melt solidification. Applying pressure on the solidification of molten metal could change melting point of alloys which enhances the solidification rate. Moreover, it refines the micro and macrostructure; it is helpful to minimize the gas and shrinkage porosities of the castings. Squeeze cast are able to produce components with relatively good mechanical properties while keeping defects low. In squeeze casting process, the molten metal is poured into the mould cavity before the two parts of the mould cavity are assembled and pressure applied until the solidification take place. (www.oit.doe.gov). the process parameter in squeeze casting therefore affects the quality of finished product and this includes pouring time, pouring temperature and the applied force. (Kenawy, 2001).

(Dhanashekar & Senthil-Kumar, 2014), carried out a review on squeeze Casting of Aluminium Metal Matrix Composites. The paper stresses the importance of squeeze casting of the Aluminium Metal Matrix Composites in all aspects: squeeze pressure, casting (melt)/ preform preheat/ die temperature, solidification rate, reinforcement particle sizes, porosity and mechanical properties. And concluded that the optimum pressure used in the squeeze casting of Aluminium alloys and composites, gives a better microstructural refinement and increase in the mechanical properties. Also suggested melt and die

 ISSN: 2645-2685

temperature during the squeeze casting of Aluminium alloys and composites should be 600°C to 700°C and around 250°C respectively. and also concluded that mechanical properties are enriched for both the alloys and the composites when fabricated through the squeeze casting technique, under controlled process parameters.

(Manikandan, 2017), Experimental Investigation on Mechanical Behavior's of Stir Cast Aluminium 6061-SiC MMC using Taguchi method orthogonal array of $L_9 3^3$. The weight fraction of SiC 6%, 9% and 12%, stirrer speed of 200 rpm, 250 rpm, and 300 rpm and reinforcement preheating temperature of 450°C, 475°C and 500°C are used. Tensile test, hardness test and impact tests were conducted on the specimens. The ultimate strength, tensile strength and yield strength are appeared in maximum level of 6% of SiC. The hardness improvement and impact values are appreciable in 12% of SiC.

(Susanta, 2014), performs the optimisation of casting parameters using squeeze casting method on LM-24 Al-Si Alloy. The optimization variables and their levels used are pressure (0 to 100MPa at an intervals of 20MPa), pouring temperature (660ºC, 700ºC and 750ºC) and die preheat temperature (200ºC and 250ºC). the investigation reveals that slower injection speed causes less turbulence and less retention of air and the applied pressure during solidification eliminates shrinkage and gas porosity, decreases thermal resistance and accelerates solidification effecting improvement in microstructure and mechanical properties of the cast material. The suitability of the process for light weight non-ferrous metal alloys has made increasing demand for this emerging process for automobile and aerospace industry

2.0 MATERIALS AND METHOD

2.1 Materials

1. Scrap Aluminium alloy were collected and used for this investigation. The composition of the scrap AL alloy was determined using energy dispersive X-ray fluorescence (EDXRF) and classical (wet analysis) methods and the results presented in Table 1.

Table 1: Chemical Composition of Al-Si Used

Sample ID	Al	Si	Cl	K	Ca	Ti	V
Al-Si	93.18	2.9	0.19	0.16	0.30	0.058	0.010

Cr	Mn	Fe	Ni	Cu	Zn	Ag	Pb
0.026	0.243	0.83	0.105	0.55	0.816	0.50	0.077

Other materials used for this research work are listed as follows:

2. Metal Mould (see Figure 1a).
3. Squeeze casting Machine (see Figure 1)
4. Thermocouple (1500 ºC Max).
5. Melting Furnace
6. Tensile Testing Machine (0.5t Mosanto Tensometer).
7. Brinel Hardness tester (Avery Hardness testing machine).
8. Izod Impact testing Machine (universal).
9. Electro-scanning micro scope. e.t.c.

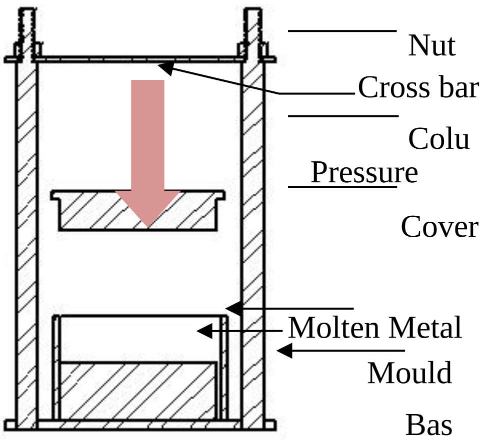


Figure 1: Squeeze Cast Machine

Figure 1a: Cast Specimen

2.2 Casting of the Specimen

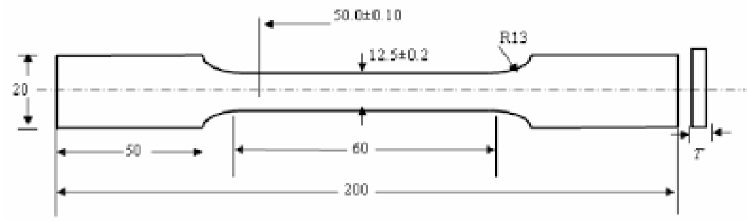
The mould was clean up, installed in the squeeze casting machine. And the preheated to a temperature of about 140ºC. The Aluminium scraps were collected and broken in smaller pieces and poured into the molten pot ($0.2m^3$) and then, temperature raised to a molten state of T_1,T_2,T_3 (see table 1). The metal mould was pre-heated to a temperature of 140°C before pouring at different cast conditions as shown in Table 1. Three thermocouples were used to observed and record the temperature of the molten Al alloy and the metal mould. The pressure applied to the mould was achieved with aid of a gauged hydraulic jack. The dimension of the Al alloy billet is 30mm x 70mm x 140 mm. The molten Al-alloy was allowed to solidify to removable temperature, then the mould was opened and the aluminium billet was removed. The process is repeated for specimen T1, T2, T3, S_1, S_2, S_3 and pressures P_1, P_2, P_3 respectively. (Table 1)

Table 2: Cast Conditions

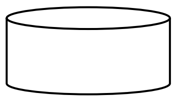
Specimen	**Cast Conditions**		
	Temperature (°C)	**Time (Min)**	**Pressure (Pa)**
Specimen 1	T1= 650	0	10
Specimen 2	T2=650	5	20
Specimen 3	T3=650	10	30
Specimen 4	S1=700	0	20
Specimen 5	S2=700	5	30
Specimen 6	S3=700	10	10
Specimen 7	P1=750	0	30
Specimen 8	P2=750	5	10
Specimen 9	P3=750	10	20

2.3 Sample Preparation

For tensile specimen the Al-cast shown in figure 2 were machined following ASTM B557-94 standard, Also, an ASTM E8-56 standard specimen was machined from the Al-cast for the hardness test and impact test respectively, (see figure 2a and 2b).



(a)



(b)

Figure 2: Sample Specification, (a) Tensile test piece, (b) hardness and impact test piece.

2.4 Chemical Analysis

The chemical analysis of the Aluminium cast was conducted at National Geosciences Research Laboratory (NGRL), Kaduna in other to ascertain the constituent elements and their proportion. A test sample was taken from all the cast samples. The result of the micro-constituent is shown in Table 1.

2.5 Mechanical Testing

Tensile, hardness and impact tests were carried out according to ASTM E8, ASTM E18 and ASTM E2248 respectively. The tensile test showed the tensile strength, yield strength, percentage elongation, reduction and the young modulus of the cast. The hardness test revealed the hardness number of the cast and impact test showed the toughness of the Al cast. Also the microstructure of the test piece were carried determined.

3.0 RESULTS

3.1 Tensile Testing Results

The results of the tensile test conducted in the laboratory of Kaduna Polytechnic, Kaduna are presented in table 3-5 and figure 3-5.

Table 3: Tensile Test Data for Specimen T1, T2 and T3

Specimen	**OXA**	**FXA (mm^2)**	**OGL (mm)**	**FGL (mm)**	**Y (kN)**	**M (kN)**	**% Elongation**	**% reduction in area**
T1	6x6 **(mm^2)**	5.5x5.8	50	55	4.6	5.0	2.18	15.97
T2	6x6	5.5x5.8	60	60.2	4.1	5.2	2	6.56
T3	6x6	5.5x5.8	55	56	3.7	4.2	1.81	6.56

where

OXA – original cross-sectional area
FOX – final cross-sectional area
OGL – original gauge length
FGL – final gauge length

Table 4: Tensile Test Data for Specimen S1, S2 and S3

Specimen	OXA (mm^2)	FXA (mm^2)	OGL (mm)	FGL (mm)	Y(kN)	M (kN)
S1	7x5	6.5x4.5	59	60	4.8	5.7
S2	8x7	8x7	55	56.5	4.2	5.3
S3	6x6	5.8x5.8	70	72	2.2	3.2

Table 5: Tensile Test Data for Specimen P1, P2 and P3

Specimen	OXA (mm^2)	FXA (mm^2)	OGL (mm)	FGL (mm)	Y (kN)	M (kN)
P1	6x6	5.5x5.8	50	55	1.0	1.5
P2	6x6	5.5x5.8	60	60.2	4.1	5.2
P3	6x6	5.5x5.8	55	56	3.7	4.2

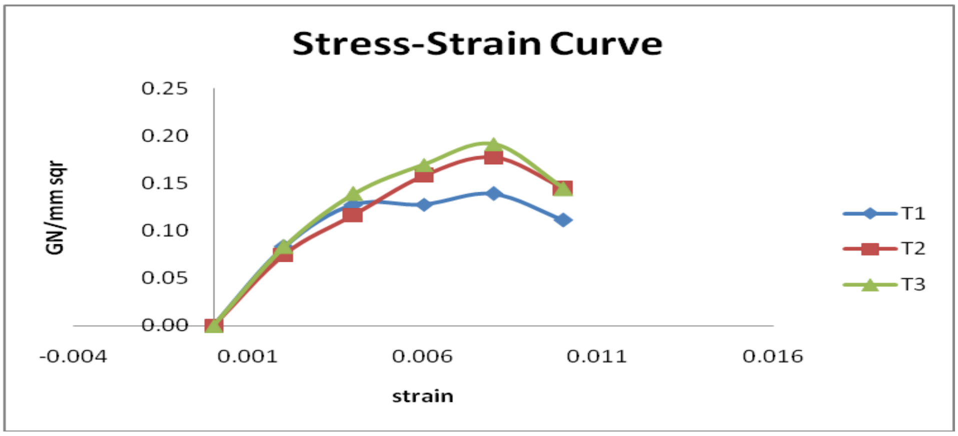


Figure 3: stress –strain curve for specimen T1,T2 and T3

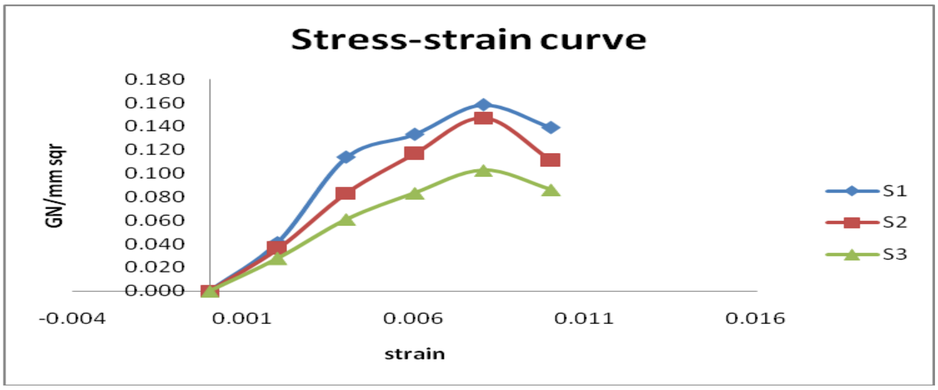


Figure 4: Stress-strain curve for specimen S1, S2 and S3.

 ISSN: 2645-2685

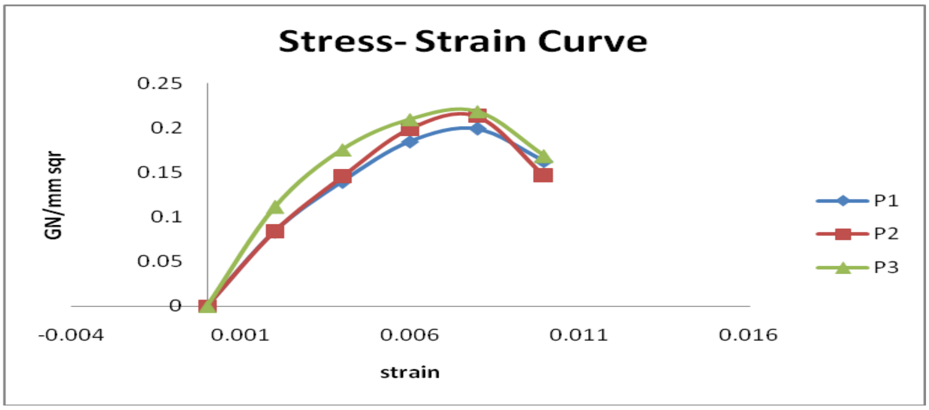


Figure 5: Stress-strain curve for specimen P1, P2 and P3.

Table 3 shows the results of mechanical properties of the Al alloy castings based on the cast condition are presented in Table 2. The maximum and minimum yield stress and UTS for pouring temperature are 169.44MPa 116.67MPa, and 183.67MPa respectively. And the maximum and minimum yield stress and UTS for pouring time are 169.44MPa 116.67MPa, and 183.67MPa respectively. While, the maximum and minimum yield stress and UTS for pressure are 188.57MPa and 214MPa respectively. The percentages of elongation and % reduction in area from the specimens are varied between 1.67 to 2.78% and 15.97% to 3.18% respectively.

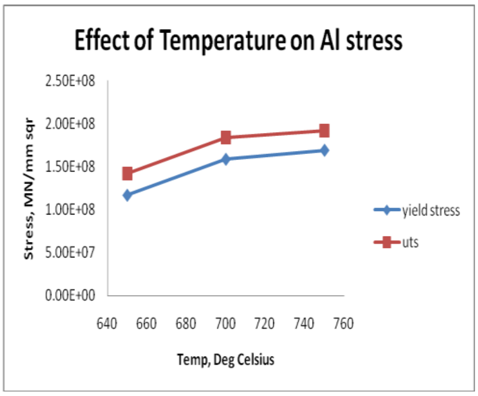


Figure 6: effect of temperature on yield and UTS of specimen T1, T2a, d T3.

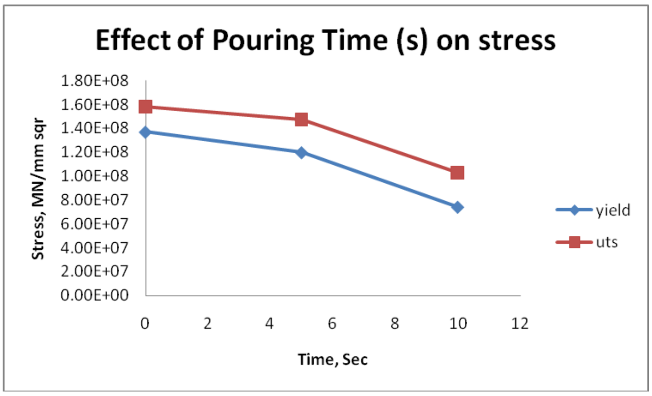


Figure 7: effect of pouring time on yield and UTS of specimen T1, T2, T3.

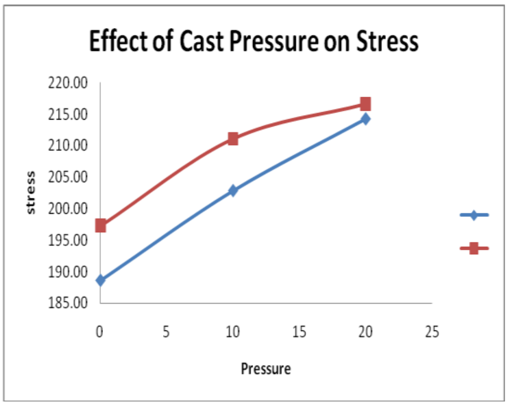


Figure 8: effect of pressure on yield and UTS of specimen P1, P2and P3.

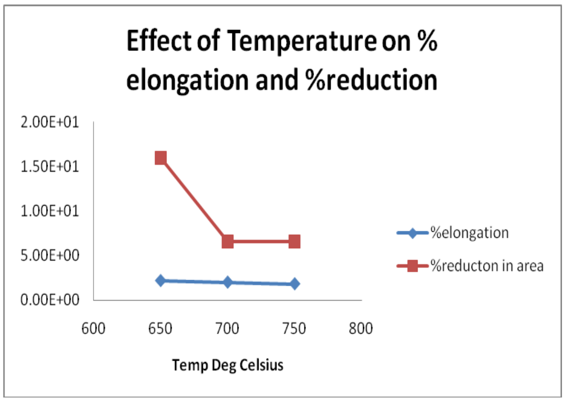


Figure 9: effect of temperature on %elongation and %reduction in area of specimen S1, S2, S3.

3.2 Hardness Testing Results

The maximum BHN is 77.06 for specimen P3 and the minimum BHN is 27.61. The effect of pouring temperature, pouring time and pressure are presented in figures 10-14.

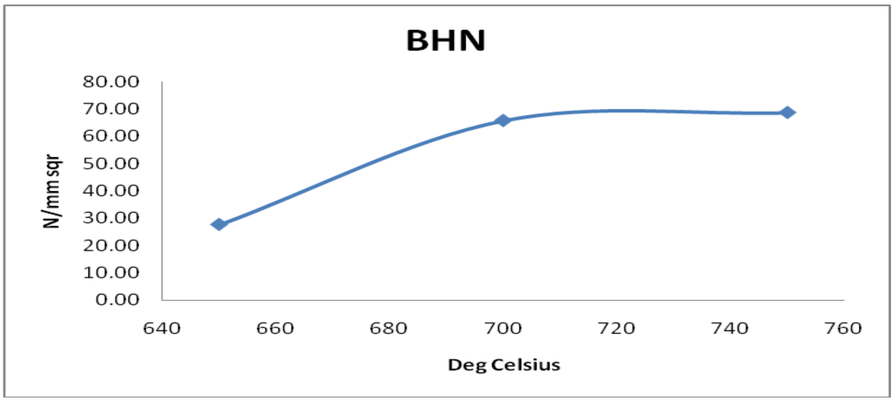


Figure 10: effect of temperature on hardness for specimen T1, T2 and T3

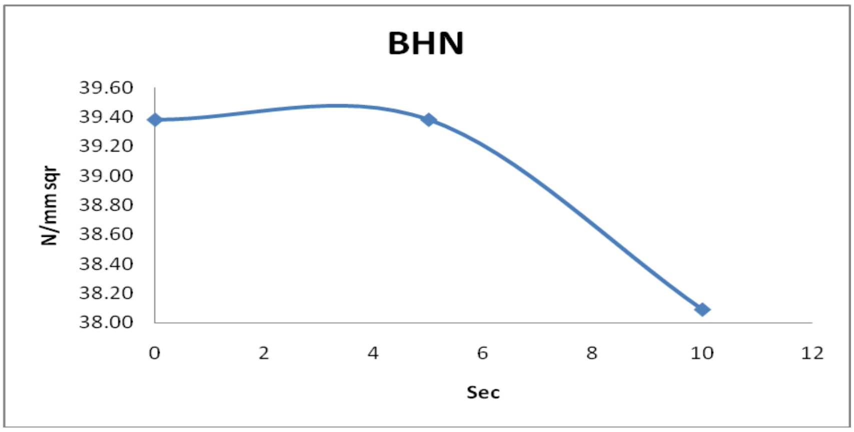


Figure 11: effect of temperature on hardness for specimen S1, S2 and S3.

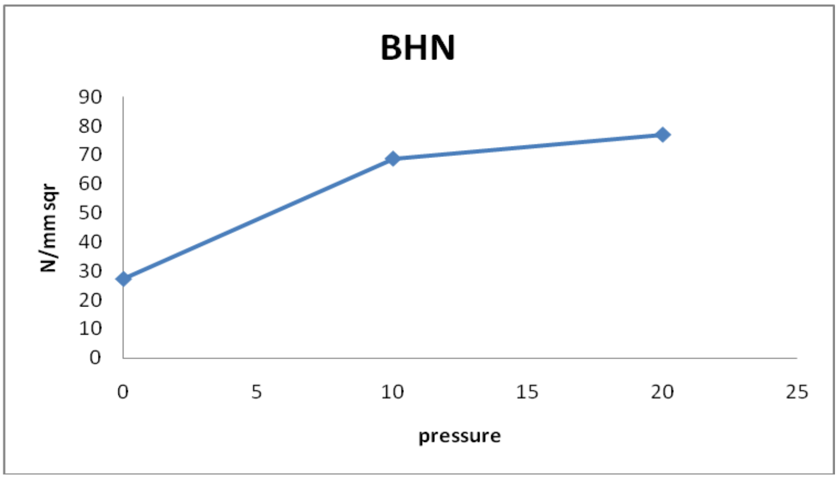


Figure 12: effect of pressure on hardness for specimen P1, P2 and P3.

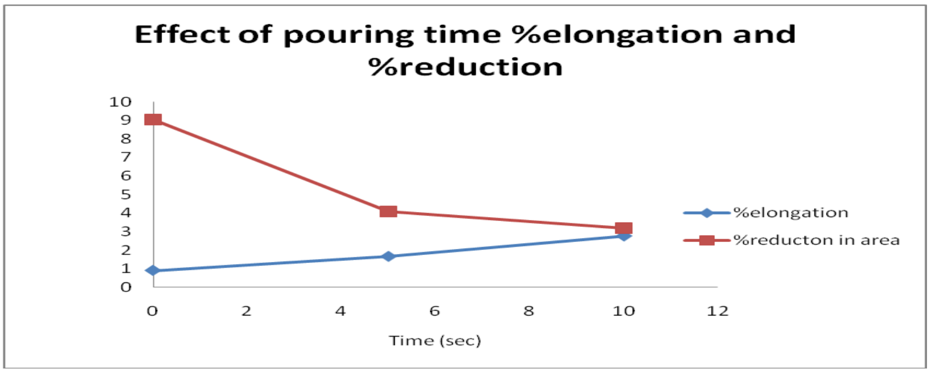


Figure 13: effect of pouring time on %elongation and %reduction in area of specimen S1, S2, S3.

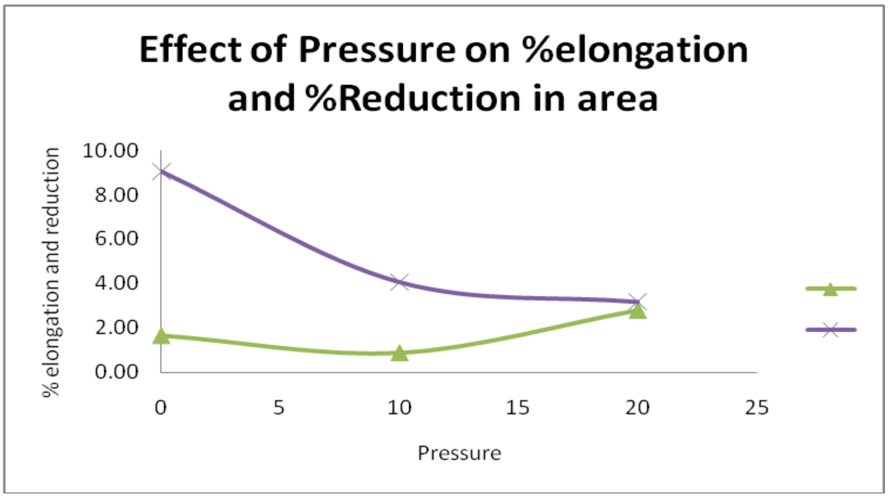


Figure 14: effect of pressure on %elongation and %reduction in area of specimen P1, P2, P3.

3.3 Impact Test Results

The results of the impact test for all the specimens are shown in figures 15-17. The maximum amount of energy absorbed is 16.06J for specimen P3, while the minimum amount of energy absorbed is 6.78J for T1 and S3.

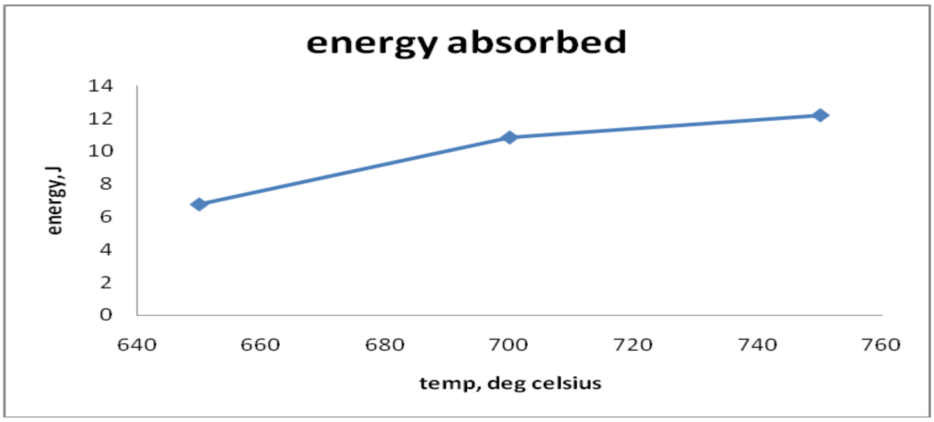


Figure 15: effect of temperature on the energy absorbed for specimen T1, T2 and T3.

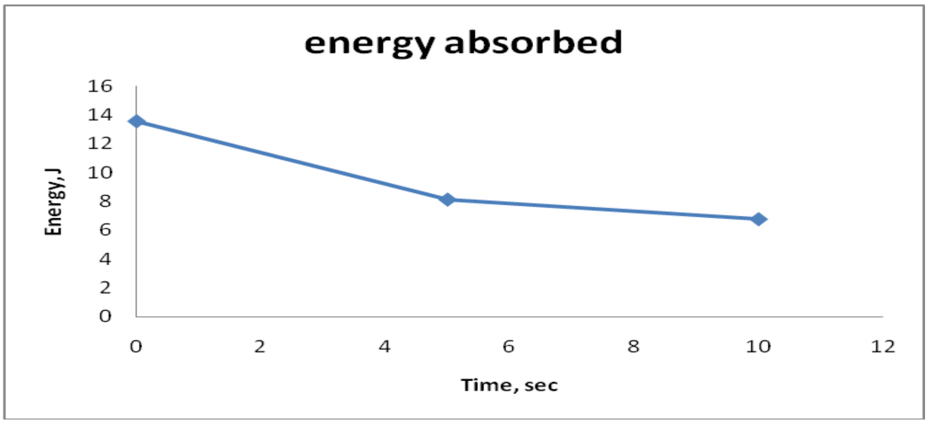


Figure 16: effect of pouring time on energy absorbed for specimen S1, S2 and S3.

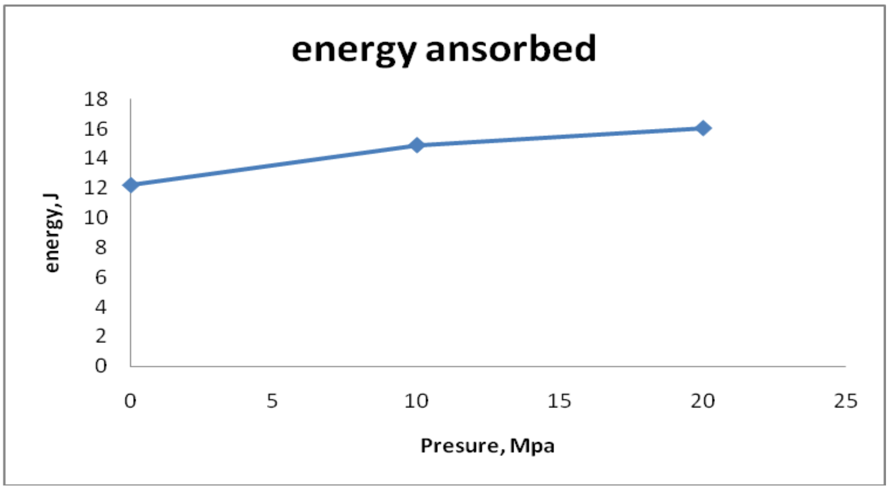


Figure 17: effect of pressure on energy absorbed for specimen P1, P2 and P3

3.4 Results of Microstructure

The results of microstructure examination taken at various magnifications are shown in figure 18 - 26. These are obtained from different cast conditions.

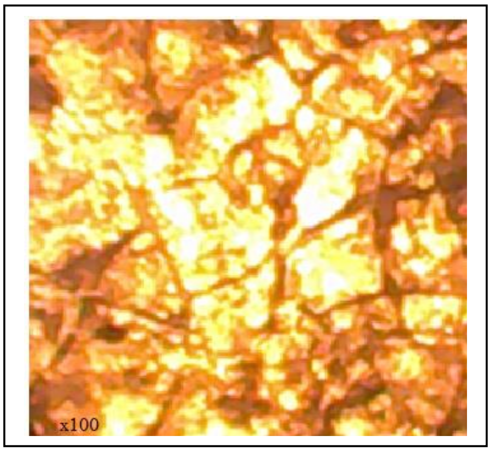


Figure 18: Microstructure of Al sample T1.

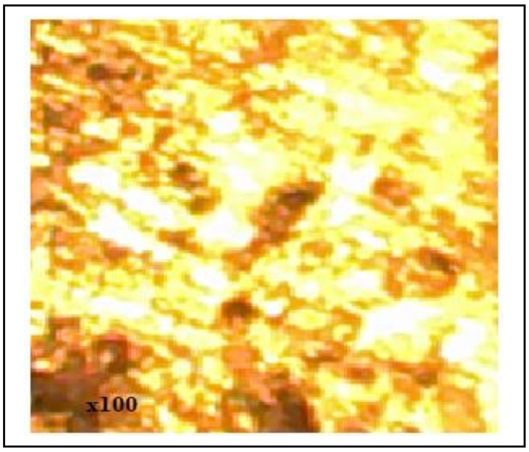
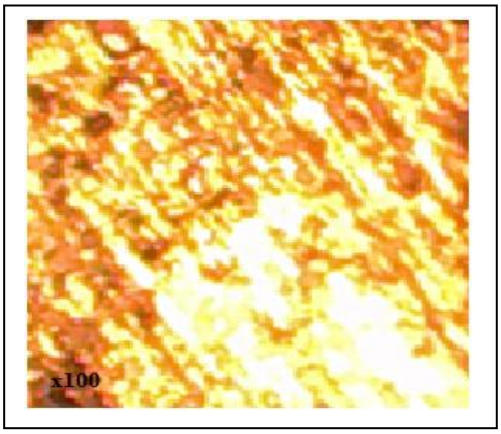


Figure 19: Microstructure of Al sample T2.



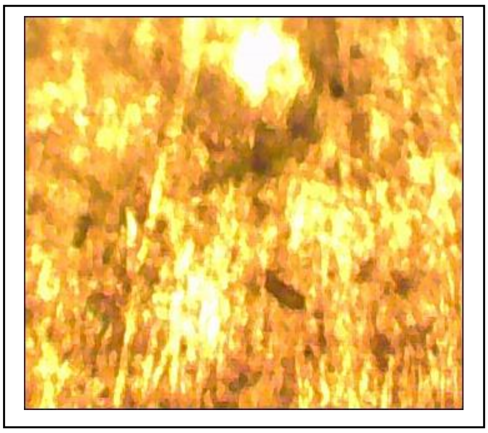
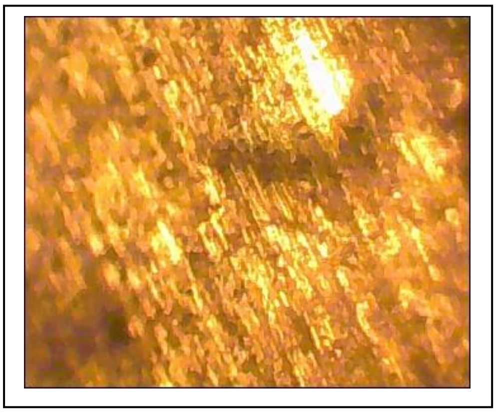


Figure 20: Microstructure of Al sample T3. Figure 21: Microstructure of Al sample S1.



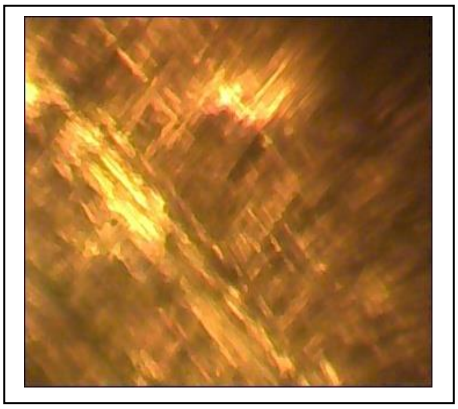
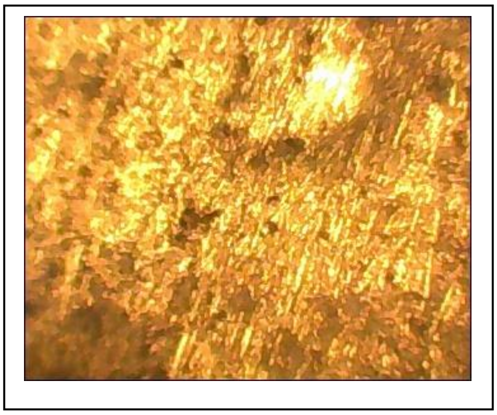


Figure 22: Microstructure of Al sample S2. Figure 23: Microstructure of Al sample S3.



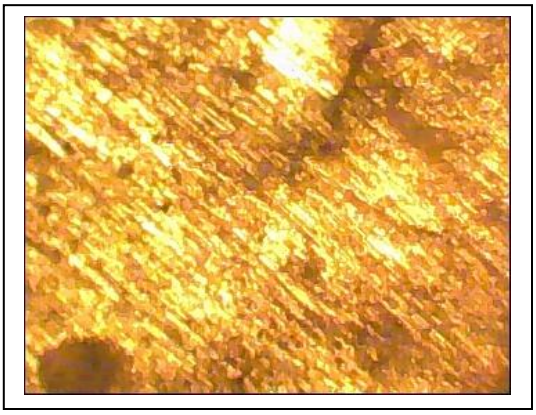


Figure 24 Microstructure of Al sample P1. Figure 25: Microstructure of Al sample P2

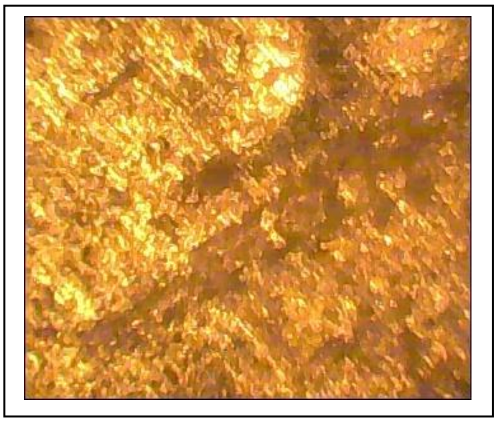


Figure 26: Microstructure of Al sample P3.

3.5 Discussion of Results

1. Effect of the Temperature

The tensile test results showed that as the pouring temperature increased the yield stress, UTS and % reduction in area increases gradually. However the % elongation decreased (see figure 6 - 9). Also the impact strength and hardness values increased with increase in pouring temperature as shown in figure 10. This result is in agreement with what is reported (Raji, A comparative Analysis of Grain Size and Mechanical Properties of Al-Si Alloy Components Produced by Different casting Methods, 2010) and (Raji & Khan 2006).

2. Effect of the Pouring Time

Figure 7, show that as the pouring time increased, the yield stress, UTS, %elongation decreased. The hardness and impact strength of the Al-alloy cast decreased and increased in pouring time respectively (see figures 12-14)

3. Effect of Applied Pressure

The mechanical properties such as yield stress, UTS, %reduction in area, impact strength, hardness of the Al-cast increased with applied pressure, while the %elongation decrease, as indicated in figures 9, 11 and 12

4. Microstructure Test Analysis

The results revealed that the grains of squeeze castings were small. The grain sizes decreased with increase in pouring temperature and increased in squeeze pressure, but increased with increase in pouring time. The grain sizes of squeeze cast products made at squeeze pressure of 10MPa were 6.63, 6.66 and 6.69 for pouring temperatures of 650, 700 and 750ºC, respectively. Increasing the squeeze pressure to 20MPa yielded finer grain sizes of 7.07, 7.46 and 7.23 for pouring time of 0min, 5min and 10min, respectively. Further increase in squeeze pressure to 150MPa did not yield any meaningful refinement for pouring temperatures of 700 and 750ºC while for pouring temperature of 650ºC yielded further refinement of grains (7.16). The fine structures of squeeze castings were brought about by the high cooling rates of the metal mold as was observed by Yong and Clegg (2004). These results agree with the findings of (Guo, Yang, & Zhang, 2012), (Murat, 2012), (Zongyi & Zhongkai, 1991) and (Muhammad, Muhammad, & Mukhtiar, 2011).

4.0 CONCLUSION

The effect of cast parameters on the mechanical properties and microstructure of the Scrap Al-alloy was investigated by squeeze cast method. The mechanical tests carried out were tensile test, hardness test and impact test, also microstructure examinations were performed. A micro constituent analysis was done to ascertain the elemental composition of the scrap Al-alloy used. The results of the microstructure showed that the microstructure of the cast increased in degree of finest as the pouring temperature and applied pressure increased and decreased with increase in pouring time. Therefore, from this investigation, it could be concluded that:

- The higher the pouring temperature the better the mechanical properties and microstructure of the Al-cast alloy.
- As the pouring time was delayed the mechanical properties and microstructure were poor.

As the squeeze pressure increased, the mechanical properties and microstructure of the Al-cast ally also increased.

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