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EFFECT OF T6 HEAT TREATMENT ON MECHANICAL PROPERTIES OF CERAMIC REINFORCED CASTED ALUMINUM ALLOY

M. Abbas [1] *, S. Nisar[1], A. Shah[1] and F. Imtiaz Khan[1]

* *muntazirbaratson@gmail.com*

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[1] **Department of Industrial Manufacturing Engineering and Management, PN Engineering College, National University of Sciences and Technology, PNS Jauhar, Karachi, Pakistan.**

Abstract: *Aluminium base alloy (Al-Cu-Si) was reinforced with silicon carbide (SiC) particles, in various percentage compositions from 0-20 wt%. Silicon carbide particle size of 20µm was selected. The molten slurry of SiC reinforced base aluminium metal was casted through green and dry sand casting methods and solidification process was carried out under ambient conditions. A selected population of total casted samples were subjected to T6 heat treatment process, followed by evaluation of mechanical properties of hardness, tensile strength and impact loading. The micro sized SiC particles were preheated up to 300C prior pouring into the melted metal, for subsequent removal of residual gases and moisture content. A continuous manual stirring method was used for homogenous distribution of reinforced particle in molten slurry. The experimental results revealed that the highest parameters of hardness, impact energy and tensile strength were achieved in the T6 heat treated specimens; having highest percentage composition (20%) of Silicon Carbide (SiC) particles.*

Keywords: *Aluminium Base Alloy (Al-Cu-Si), Silicon Carbide (SiC), Particle reinforced metal matrix composite (PMMC), T6 Heat Treatment, Artificial Aging*

1. INTRODUCTION

Cast aluminium alloys have widespread utilization in automobile and aerospace industries due to their salient properties of cast-ability, high strength to weight ratio, weld-ability, mechanical properties and corrosion resistance. Aluminium casting is the most cost effective solution to many critical requirements in fabrication of industrial and domestic equipment, machines, appliances, vehicles and super structures [1]. Use of particulate reinforcements of various types in base aluminium alloys is very frequent; in order to enhance the specific mechanical properties of metal matrix composites. Aluminium alloy Al-Si-Cu is one of copper based, heat treatable aluminium alloy which has extensive use in automobile industry. The treatment of this alloy has a significant effect on enhancement of specific mechanical properties. T6 heat treatment is the one among most widely used heat treatment methods for aluminium alloys; casted through sand and die casting processes. This treatment process (T6) is consists of metal heating at an elevated temperature followed by quenching process and artificially ageing [2] .

The reinforcement of a high strength, high hardness ceramic material in aluminium alloys is frequently used in modern research practices; to achieve the enhanced mechanical properties. The amalgamation of micro-sized particulate of silicon carbide (SiCp) into the base aluminium alloys has resulted in a high strength and low cost composites material over the monolithic counterparts [3]. Particulate reinforced metal matrix composites (PMMCs), holds a better plastic forming capability to enhance the material hardness due to homogeneity in distribution of reinforced particles in the matrix, as compared to whisker & fibre reinforced composites. [4]. The selection of casting method and process of solidification; has a vital role to determine the surface finish, microstructures and the mechanical properties of MMC. Enhanced cooling rates for solidification plays a pivotal role in deciding the quality of cast. Improvement in quality of casted parts can be achieved by application of several techniques during casting and solidification processes. A qualitative casting process can results in reduction of dendrite arm spacing (DAS) on casted surfaces, which ultimately accounts in aggravation of the material

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hardness and tensile strength [5] . In addition, the quality of surface and microstructures of casted aluminium parts are highly dependent on chemical composition of material, casting process and solidification rate [1].

The copper based aluminium alloys are enormously used in manufacturing industry, especially in auto engine components, cylinder heads, pistons cylinder blocks and piston rings. Over the period of time, this usage has increased exponentially due its improved metallurgical properties; through heat treatment in particular. Additions of Silicon carbide particles (SiCp) in metal alloys improve mechanical properties because of their inherited features like high hardness, elastic modulus, tensile strength, and wear resistance. Enhancement in mechanical properties of SiC reinforced aluminium composites is highly depends on shape, size and distribution of reinforcement in the matrix. [6]. The reinforcement of ceramic compounds into aluminium alloys also restrains the growth of pores however; extensive reinforcement volumes of SiC particles may results in increasing pore count, which can be a reason for reduction of mechanical properties and density [7]. During the various casting processes, the reinforced particulates are preheated to a certain temperature for removal of moisture content and residual gases prior amalgamation with the melted aluminium metal so that the extrusion of entrapped gases and other oxidizing factors could be to reduce to a minimal fraction [8].

To achieve a refined quality cast, it is very essential to select the most reputable casting process, leading to formation of defects free products. Copper based Aluminium alloy (Al-Cu-Si), can be casted in all casting processes however, most commonly used and preferred techniques are the sand, die and permanent /semi-permanent mould casting [9]. Tensile properties of Aluminium alloys are significantly affected by the heat treatment and its period at the elevated temperature. T6 heat treatment process for aluminium alloys encompasses the elevated temperature heating, quenching in water and artificial ageing at a moderate temperature normally above 100 C. The pre-setting condition for quench process includes the quench temperature, which has a vital impression on the subsequent mechanical properties of treated material. [10]

The presence of dense and tough oxide layer on the aluminium melt during casting process reduce its fluidity. This undesired phenomenon can be reduced to a great extent either by alloying certain elements like magnesium or by use of relevant flux material and degasser. Addition of modifiers like Strontium, antimony, sodium or magnesium to the hypo-eutectic state of Al-Si alloys have substantial impacts on improvement of surface microstructures, grain boundaries and surface finish [11]. The presence of hydrogen content during the melting of metal may lead to aggravated porosities and surface defects in aluminium casts. Scavenging of metal melt with argon gas and continuous use of chlorine or fluorine base degassers during casting process are common methods for removal of hydrogen gas prior pouring melt in to moulds. [12].

Alloys subjected to T6 Heat treatment process acquire the highest material strength, without sacrificing other desired mechanical properties, which are essential for engineering applications. [13]. The highest mean parameter of elongation, tensile strength and yield strength were achieved in water quenching temperature at 30C to 55C. [10]. Moreover, for acquisition of superior mechanical by T6 treatment, the high temperature heating at 540C for 4 hour can be the optimal condition in case of Silicon based aluminium alloys [14]. Homogenous mixing/stirring is a very crucial step in ceramic reinforced casting methods; which may otherwise can lead to high surface porosities and reduction of mechanical properties especially thermal-fatigue life; due to higher crack propagation rates in the defected regions. [15]. The T6 process of Aluminium alloys having solution treatment temperature of 503C results in higher hardness values when artificial ageing was conducted at 175-225 C for 10 hours [16]. Quenching media and its temperature has a significant impact on the surface structures and mechanical properties of aluminium casts. Normally used mediums for quenching process are water, several oils, brines, burnt oil etc. Quenching in salt brine is although more rapid

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than water and oil but, it was not recommended for complex and thin sections where oil and water quenching is more superior due to minimal crack propagation and distortion [4].

2. MATERIAL AND EXPERIMENTATION

Aluminium base alloy (Al-Cu-Si) is used during this research study. It is a heat treatable, copper based aluminium alloy. Table-1 below shows the material composition of selected base metal.

Billets of copper based aluminium alloy (Al-Cu-Si) were cut into smaller pieces and allowed for melt in a graphite crucible on a Gas furnace. The temperature was maintained at 750 C for a complete dissolution of all ingredients of base metal. Green and dry sand casted processes were used for metal casting. The grinded silicon carbide (SiC) particulates of 20µm were preheated to 300 C for 30 minutes for removal of moisture content and entrapped surface impurities/gases prone to oxidation during casting process. The requisite percent composition (0, 10, 20 wt % respectively) of moisture free, heated particles of SiC were injected in the melted copper base aluminium (Al-Cu-Si) as per the sequence of experiments. The casting process was separately undertaken for various reinforcement compositions of 0 %, 10% and 20 % SiC in the molten base metal however, casting processes (green and dry sand) and all other ambient conditions remained similar. A continuous stirring process was carried out for 10 minutes for homogenous distribution of SiC particles with molten base metal(Al-Cu-Si) constituents. The stirring method is not only helpful in avoiding accumulation of undissolved particle in the bottom of the melts but it also restricts precipitation of SiC particle on cast surfaces. During the entire casting process, the molten metal was continuously treated with degassing agents and coverall flux to remove entrapped gases and avoid surface oxidation. The temperature of homogenised slurry was slightly reduced for addition of 1% of magnesium, which

Table 1. Chemical composition of Base Aluminum Alloy

Cu	Mg	Si	Fe	Mn	Ni	Zn	Sn	Pb	Ti	Al
3.44	0.19	7.09	0.58	0.16	0.01	.08	0.1	0.02	0.01	Remaining

Fig.1. Green/ Dry Sand Casted samples (size of cast 1x1x8 in)

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acts as a modifier. Magnesium content is an aiding factor to improve the surface grain structure and castability. The temperature of slurry was raised to around 700 C for a short interval, followed by pouring into green sand and dry sand moulds. Both green and dry sand casting moulds were kept at ambient temperature of 35 C. To curtail certain casting defect and to achieve an optimized surface finish the moulds were tilted at an angle of 15 degree with respect to ground prior pouring molten slurry. Moulds were allowed to solidify till the equilibrum temperature of 35C was attained.

The selected dimensions for all cast parts were 1x1x8 inch, as shown in Fig-1. These casted parts were subjected to machining process as per the sample requirements of Vicker's hardness test (HVN), Ultimate tensile strength (UTS) and Charpy impact loading test. A selected population of machined samples having various reinforced SiC compositions (0, 10 20 wt %) were subjected to T6 heat treatment. During this T6 treatment the specimens were heated at an elevated temperature of 540 C for 4 hours in an electric oven, followed by quenching in water at 35 C. These quenched specimens were then subjected to artificial aging in an electric furnace at 270 C for 6 hours. Thereafter, the samples were allowed to cool naturally under ambient conditions.

3. RESULTS AND DISCUSSION

The objective of this research study is to evaluate/analyse the effects of T6 heat-treated as well as reinforcement of various percentage compositions of SiC particles on mechanical properties (hardness, tensile strength and impact energy) of Al-Cu-Si Aluminium alloy.

3.1. Mechanical Tests

The selected numbers of green and dry sand

Fig.2. (a) Hardness Test samples (b) Impact loading samples (c) Tensile strength test samples

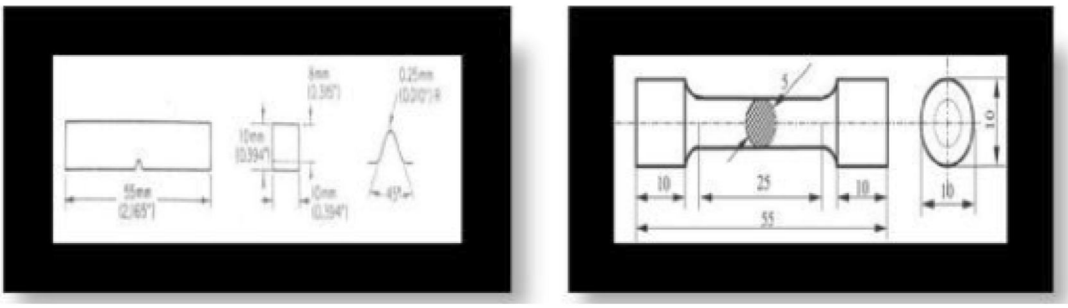

Fig.3. (a) Dimensions for Charpy test sample (b) Dimensions for UTS test sample

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casted specimens having various percentage composition of SiC reinforcement were heat treated (T6) after shaping the samples in accordance with the requirements of selected mechanical tests. The machined specimens and their dimensions for mechanical tests as shown in Fig-2 & 3.

3.1.1. Hardness Test

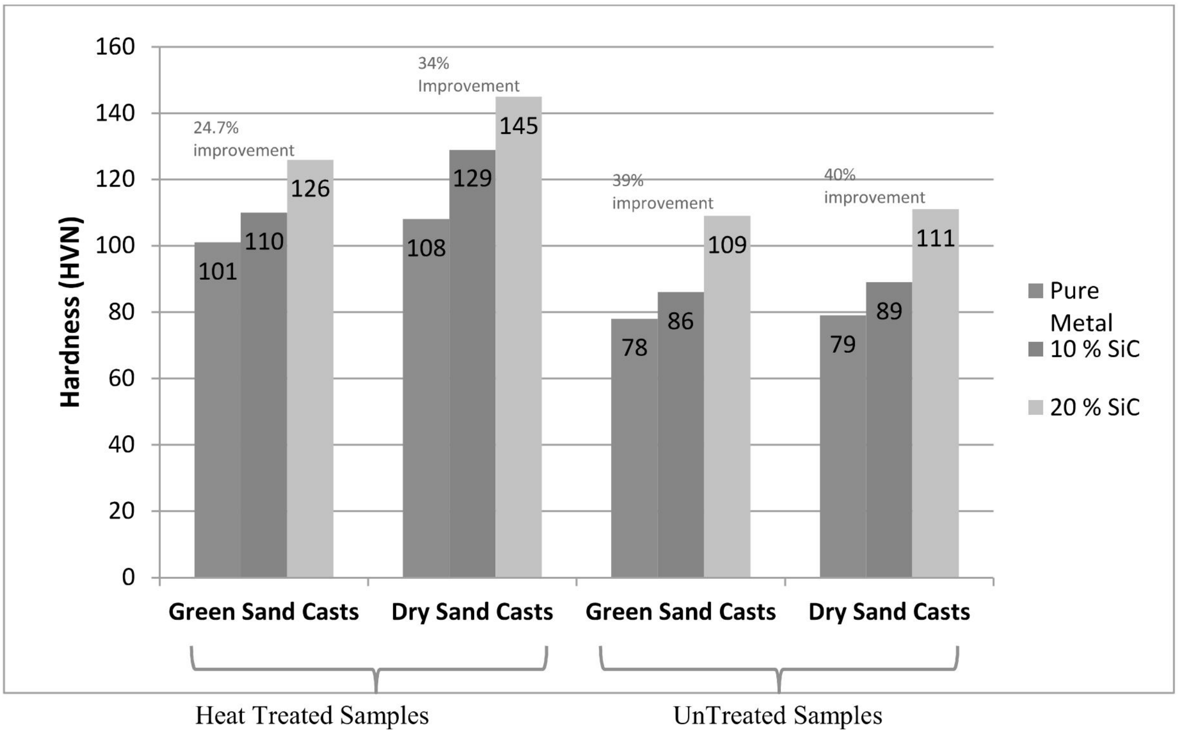
In hardness test, the samples were cut into cuboids (dimensions 1x1x1 in) as shown in Fig-2 (a). The tested surfaces of all specimens (heat treated & untreated) were grinded and polished prior subjecting to Vickers hardness test. Graph-1 below depicts the Vickers hardness numbers (VHN) for all type of specimens.

Above results indicates that the hardness number has improved with the increase in reinforcement percentage of SiC particles. This increment has further augmented by application of T6 heat treatment process. In short, peak hardness values were achieved in the heat treated samples having maximum SiC reinforcement (20 % SiC). It can also be deduced that the casting process has a significant effect on the hardness number. Despite having the same percentage of SiC particles reinforcement, dry sand casted samples have attained a higher value of hardness as compared to the samples of green sand casting process.

3.1.2. Impact Loading Test

As per the ASTM standards, the Charpy impact test samples were machined (size 10×10×55 mm) and notch at an angle of 45 degree in the centre of sample as shown in Fig-3 (a). Graph-2 below depicts the impact energy parameters for all type of samples.

Graph 2 shows that, in case of the T6 heat treated samples, the impact energy has increased with the increase in SiC reinforcement. This increase can be accredited to the appearance of



Graph.1. Results of Vickers Hardness Number

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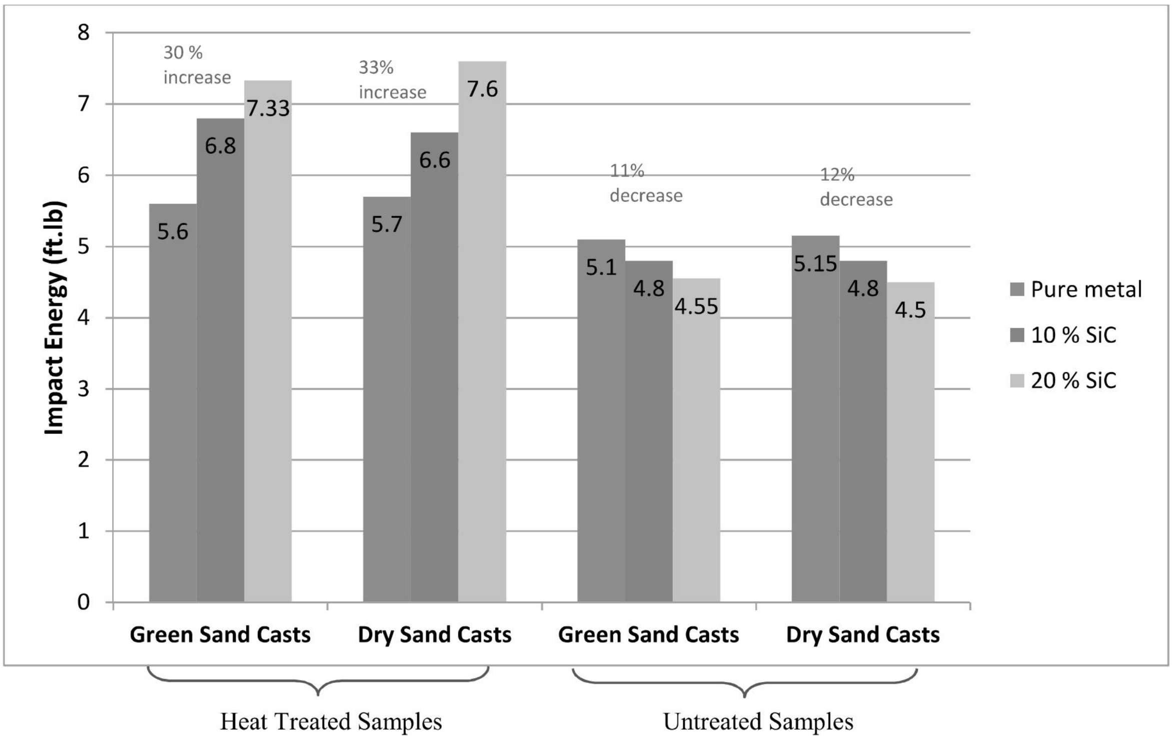

Graph. 2. Results of Impact loading energy- Charpy test

recrystallization during high temperature heating phase of T6 treatment, in which rearrangement of the incoherent intermetallic bonding takes place which ultimately can increase the impact energy. However, in case of untreated specimens, the impact energy has slightly reduced with addition of SiC particles. This slight reduction can be attributed to increase in brittleness of subsequent composite material due reinforcement of a non-metallic brittle ceramic compound i.e. SiC. Low homogenisation and weak interfacial bonding between base metal and reinforced SiC may also contribute significantly for decline in impact energy.

3.1.3. Tensile Strength Test

The samples for tensile test were machined into a requisite shape for UTS tests, as mentioned in Fig-3. Samples were placed in the test machine and the scale was adjusted to minimise the equipment error followed by load application till appearance of permanent deformation/breakage. The test results were repeated thrice for accurate average mean values. Graph-3 shows the test results.

The results in Graph-3 are a perfect representation of enhancement of ultimate tensile strength (UTS), due reinforcement of homogenously dispersed micron sized silicon carbide (SiC) particulates in base aluminium alloy (Al-Cu-Si). In addition, it shows that the T6 heat treatment has further augmented the tensile strength parameters. The increasing trend of UTS can be attributed to the formation of strong inter-metallic bonding between the copper base metal alloy (Al-Cu-Si) and the reinforced high strength material (SiC). The inequality in coefficient of thermal expansion between the aluminium alloy and silicon carbide particulates tends to yield thermal stresses, which appears primarily as plastic deformation of matrix and catalysis the initiation of high dislocation density. This phenomena in turns, is a reason for enhancement in ultimate tensile strength of composite material matrix.

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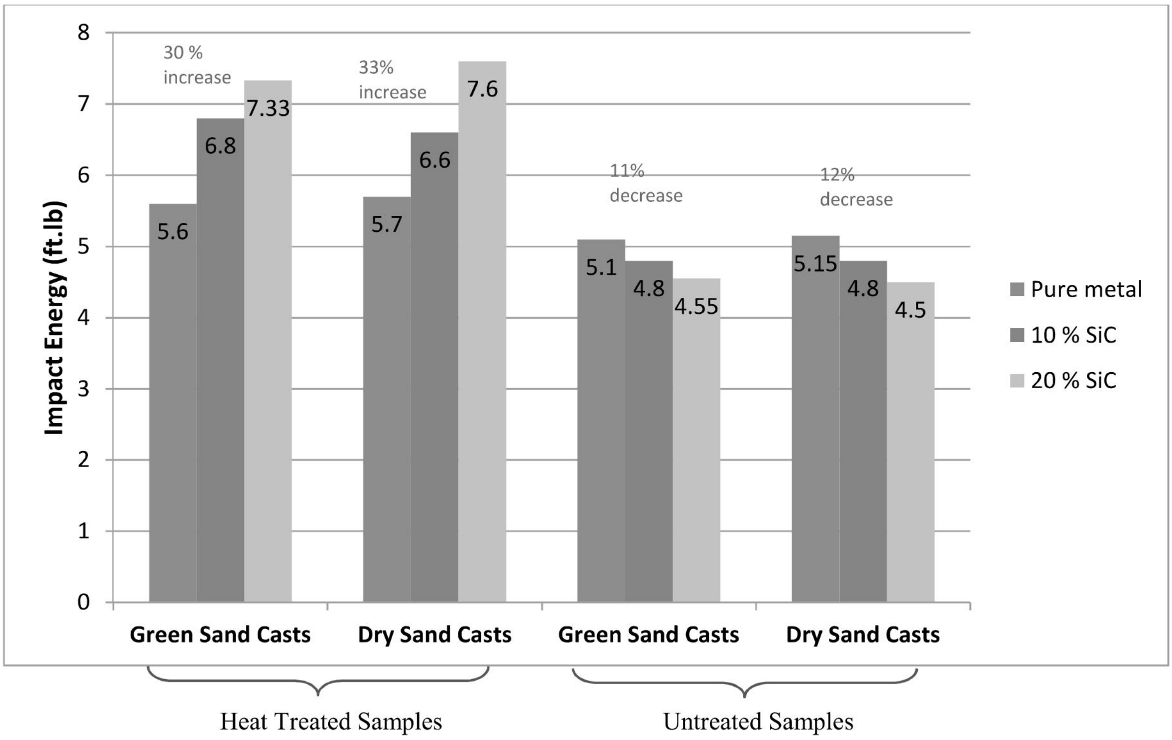

Graph. 3. Results of Ultimate Tensile Strength (UTS)

4. CONCLUSION

The following conclusions have been deduced:

a. The T6 heat treated specimens having highest SiC reinforcement (20 wt%) have shown superior parameters of mechanical properties (tensile strength, hardness) as compared to untreated specimens of pure base aluminium alloy (Al-Cu-Si).

b. In case of untreated samples, impact energy has slightly reduced (maximum 12%) with an increase in SiC reinforcement. However, after application of T6 heat treatment process impact energy has improved not only in samples of pure base aluminium alloy but also in SiC reinforced aluminium alloy samples. This enhancement is resultant of rearrangement of the incoherent intermetallic bonding. Maximum improvement in impact energy was noticed in heat treated specimens having highest SiC reinforcement.

c. In short, the T6 heat treatment process has improved hardness, tensile strength and impact energy of SiC reinforced as well as unreinforced samples

d. Approximately at all points, hardness was found proportional with the tensile strength. Above is valid for both green and dry sand casting processes.

e. During the entire experimentation process, it was revealed that all the mechanical test parameters of dry sand casting process were found slightly superior than the green sand casting process.

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REFERENCES

1. Shabestari, H. M. S. G., "Effect of copper and solidification conditions on the microstructure and mechanical properties of Al–Si–Mg alloys," Journal of Materials Processing Technology, no. 153–154, pp. 193-198, 2004.
2. Sjolander, S. S. E., "Optimisation of solution treatment of cast Al–Si–Cu alloys," Materials and Design , vol. 31, p. S44–S49, 2010.
3. Sunday Aribo, J. A. O. D. O. F., "High Temperature Mechanical Properties of Silicon Carbide Particulate Reinforced Cast Aluminum Alloy Composite," Leonardo Electronic Journal of Practices and Technologies, pp. 9-16, 2011.
4. Ashutosh Sharma, S. D., "Study of age hardening behavior of Al–4.5 wt%Cu/zircon sand composite in different quenching media," Materials and Design 30 , p. 3900–3903, 2009.
5. Shao-chun, S., "Effects of moulding sands and wall thickness on microstructure and mechanical properties of Sr-modified A356 aluminum casting alloy," June 2012.
6. Sajjad Amirkhanlou, B. N., "Fabrication and characterisation of A356/SiC semi solid composites by injecting SiCp containing composite powders," Journal of Materials Processing Technology 216, pp. 841-847, 2012.
7. Tekmen, I. O. C. K. O. C., "The mechanical response of Al-Si-Mg/SiC composite: Influnence of porosity," Materials Science and Engineering A360 , pp. 365-371, 2003.
8. Viswanatha, M. P. K. S. B. T. S. K. B. M., "Mechanical property evaluation A356/SiCp/Gr Metal matrix composite," Journal of Engineering Science and Technology Vol. 8, No. 6, pp. 754 - 763, 2013.
9. Boyer, H. E., "Metals Handbook," American society for Metals, pp. 6-49, 1991.
10. Shushi, "A Methodology to Predict the Effects of quench rate on mechanical properties of Aluminum Alloy," pp. 6-8, May 2006.
11. Rathod, J. V. N. R., "Effect of modifyers anf grain refiner on cast Aluminium alloy," International Journal of emerging trends in engineering and development issue 2 vol 5, 2012.
12. Schey, J. A., "Introduction to Manufacturing Process," pp. 200-201, 2000.
13. Timothy, H. E. B. and Gall, L., "Heat Treating of Non Ferrous Alloys," in Metal Hand book, Ohio, American Society of Metals, 1991, pp. 28-82.
14. Dewhirst, "Optimisation of Heat Treatment of Semi Solid processed A-356 Aluminium Alloy," Master Theises, 2005.
15. Arami, R. K. M. A. F. K. H., "Microporosity control and thermal-fatigue resistance of A319 aluminum foundry alloy," Materials Science and Engineering A 472 , p. 107–114, 2008.
16. Mahmudi, P. S. H. G. R., "Improved properties of A319 aluminum casting alloy modified with Zr," Materials Letters 60, pp. 2606-2610, 2006.

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