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A356 Aluminum Alloy and applications- A Review

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ABSTRACT

A356 alloys are ever more accepted in aircraft and automobile due to their high strength-to-weight ratio and its thixotropic structure (designated SSM-A356). Its specific tensile strength and rigidity are superior to other Aluminum alloys. These qualities lead to less vehicle and aircraft weight and better fuel economy. A356 based alloys have been developed with significant ductility, strength, elongation, hardness and toughness at room temperature in as-cast state. Therefore, in the present work an attempt has been made to review A356-alloy based systems and it application that possesses exceptionally high ductility as well as good mechanical strength

1. Introduction

A356 alloys are alloys wherein aluminium (Al) is the major metal. The distinctive alloying elements are copper, magnesium, manganese, silicon and zinc. There are two major classifications, namely casting alloys and wrought alloys, both of which are supplementary subdivided into the categories heat-treatable and non-heat-treatable [1]. In relation to 85% of aluminium is used for wrought products, for illustration rolled plate, foils and extrusions. Cast aluminium alloys give up cost-effective products due to the low melting point, even though they usually have lower tensile strengths than wrought alloys. The nearly everyone significant cast A356 alloy system is Al–Si, where the high levels of silicon (4.0–13%) give to give good casting characteristics. A356 alloys are broadly used in engineering structures and components where light weight or corrosion resistance is necessary. Alloys collected typically of aluminium have been very important in aerospace manufacturing as the introduction of metal skinned aircraft. Aluminium-magnesium alloys are lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium. A356 alloy surfaces will invent a white, protective layer of corrosion aluminium oxide if missing unprotected by anodizing and correct painting procedures. In a wet environment, galvanic corrosion can happen when an A356 alloy is to be found in electrical contact with other metals with more negative corrosion potentials than aluminium, and an electrolyte is present that allows ion exchange. Aluminium alloys can be unacceptably heat treated. This causes internal element separation and the metal corrodes from the inside out. Aircraft mechanics deal daily with A356 alloy corrosion [2-4].

A356 alloys naturally have an elastic modulus of about 70 GPa, which is about one-third of the elastic modulus of the majority kinds of steel and steel alloys. Therefore, for a specified load, a part of an A356 alloy will experience a greater elastic deformation than a steel part of the identical size and shape. Though there are A356 alloys with somewhat-higher tensile strengths than the usually used kinds of steel. With completely new metal products, the design choices are often governed by the choice of manufacturing technology. Extrusions are mainly important in this view, due to the effortlessness with which A356 alloys can be extruded to form complex profiles. In general, stiffer and lighter designs can be achieved with A356 alloys than is possible with steels. In automotive engineering, cars made of A356 alloys employ space frames made of extruded profiles to ensure rigidity. This represents a radical change from the common approach for current steel car design, which depends on the body shells for stiffness, known as unibody design [5-8].

2. Literature Reviews

N. Natarajan et al. presented [1] the wear behaviour of aluminium metal matrix composite (Al MMC) sliding against

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automobile friction material has been compared with the conventional grey cast iron. The wear tests have been carried out on a pin on disc machine, using pin as brake shoe lining material and discs as A356/25SiCp Al MMC and grey cast iron materials. Pins of 10mm diameter have been machined from a brake shoe lining of a commercial passenger car. The grey cast iron disc has been machined from a brake drum of a commercial passenger car. The Al MMC disc has been manufactured by stir casting technique using A356 aluminium alloy and 25% silicon carbide particles and machined to the required size. The friction and the wear behaviour of Al MMC, grey cast iron and the semi-metallic brake shoe lining have been investigated at different sliding velocities, loads and sliding distances. The worn surfaces and sub-surface regions of MMC, the cast iron and the lining have been analysed using optical micrographs. The present investigation shows that the MMCs have considerable higher wear resistance than conventional grey cast iron while sliding against automobile friction material under identical conditions. A gradual reduction of friction coefficient with increase of applied load is observed for both cast iron and Al MMC materials. However, in all the tests it is observed that the friction coefficient of Al MMC is 25% more than the cast iron while sliding under identical conditions. The wear of the lining material has been observed more when sliding against MMC disc because of the ploughing of the lining material by the silicon carbide particles. The wear grooves formed on the lining material while sliding against MMC and cast iron have been analysed using optical micrographs. D. Cree et al. [2] evaluated the dry sliding wear and friction behaviors of A356 aluminum alloy and a hybrid composite of A356 aluminum alloy and silicon carbide foam in the form of an interpenetrating phase composite using a ball-on-disk apparatus at ambient conditions. The stationary 6.35 mm alumina ball produced a wear track (scar) diameter of 7 mm on the rotating specimen surface. Three different loads; 5 N, 10 N and 20 N were applied at a constant sliding speed of 33 mm/s for both materials. Wear tracks were characterized with a scanning electron microscope and measured with an optical surface profilometer. In general, this novel A356/SiC foam composite reduced the friction coefficient and wear rate from that of the base alloy for all loading conditions. In addition, as the load increased, the friction coefficient and wear rate decreased for both materials. Rong Chen et al. [3] investigated the fretting wear behavior of an A356 aluminum alloy reinforced by 15 vol.% 10 mm silicon carbide particle with and without T6 heat treatment, when tested against a bearing steel ball SJU2-QT. at different applied loads 5–20 N. and fretting cycles 104–106 cycles under a ballrflat contact. It is proven that T6 heat treatment of composites offers better fretting wear resistance compared with that without heat treatment. The effect of load on the fretting wear damage reveals that the wear loss volume of the composite is increased with the increase of the load. At higher load, the aluminum matrix in the composite is transferred from the composite to the counterface steel ball. However, at low load, the SiC particles in the composites have high probability to abrade the steel ball seriously. After long cycle duration, the plastic deformation of the composite becomes more serious; meanwhile, the debris transferred from the steel ball to the composite is accumulated. SuchetaNagarajan et al. [4] shown that SiC reinforcements can act as heterogeneous nucleation sites for Si during solidification of Al–Si–SiC composites. The present study aims at a quantitative understanding of the effect of SiC reinforcements on secondary matrix phases, namely eutectic Si, during solidification of A356 Al–SiC composites. Effect of volume fraction of SiC particulate on size and shape of eutectic Si has been studied at different cooling rates. Results indicate that an increase in SiC volume fraction leads to a reduction in the size of eutectic Si and also changes its morphology from needle-like to equiaxed. This is attributed to the heterogeneous nucleation of eutectic Si on SiC particles. However, SiC particles are found to have negligible influence on DAS. Under all the solidification conditions studied in the present investigation, SiC particles are found to be rejected by the growing dendrites. R. RahmaniFard et al. [5] investigated the effect of extrusion temperature on the microstructure and porosity of Al A356-10 vol.%SiC composites. Composites containing three different particle sizes of 38, 62 and 82 m fabricated by compocasting (SL) method were extruded at three different temperatures of 450, 500, and 550 ◦C using an extrusion ratio of 18:1. The extruded composites exhibited reduced porosity as well as a more uniform particle distribution when compared with the as-cast samples. Arda C¸ etin et al. [6] attempted to study the effect of solidification rate on cluster formation in an Al–Si–Mg (A356) alloy composite reinforced with SiC particles and to explore the applicability of spatial functions to PMMC microstructures to quantify the degree of clustering. The observed amount of clustering in composites was evaluated with the nearest neighbour and local density statistics in terms of variations in dendrite arm spacings and solid fractions at the dendrite coherencies. The results indicate that the distribution of SiC particles is controlled by the secondary dendrite arms. Depending on dendrite arm spacings and particle content, clustering is most pronounced at distance scales ranging approximately between 150 and 500 m, which are much larger as compared to the nearest neighbour distances. S. P. Dwivedi et al. [7] focused on the fabrication of aluminum matrix composites reinforced with various weight percentages of SiC particulates and Fly-ash by modified electromagnetic stir casting route. The distribution of SiC and Fly-ash particles in the matrix was improved by providing externally argon gas into the melt during electromagnetic stirring. Five samples of hybrid composite with different combination of Fly-ash and SiC (25 lm) were prepared by electromagnetic stir casting method. Mechanical properties (tensile strength, hardness, toughness and fatigue strength) and microstructure of all five samples were analyzed. Microstructure presents that the reinforcements (SiC particulates and Fly-ash) are uniformly distributed in the matrix (A356). The results reveal that sample of A356/15 %SiC/5 % Fly-ash shows best result among all the selected samples. Density, porosity, specific strength and thermal expansion were also calculated to see the effect of Fly-ash addition. S. P. Dwivedi et al. [8] investigated the effect of CNC lathe process parameters like cutting speed, depth of cut, and feed rate on surface roughness during machining of A356 alloy 5 wt% SiC particulate metal-matrix composites in dry condition. Response surface methodology (Box Behnken Method) is chosen to design the experiments. The results reveal that cutting speed increases surface roughness decreases, whereas depth of cut and feed increase surface roughness increase. Optimum values of speed (190 m/min), feed (0.14 mm/rev) and depth of cut (0.20 mm) during turning of A356 alloy 5 wt% SiC composites to minimize the surface roughness (3.15>µm) have been find out. K. Abedi et al. [9] study investigated the formation of Fe containing intermetallic compounds on the microstructure and tensile properties of A356–10% SiC composite in the Mn- and Sr-modified conditions. The composite ingots were made by stir casting process and iron was added to the remeltedcomposites at different concentrations varied from 0.5 to 2%. For 2 wt.% Fe, different levels of Mn were added to identify the optimum Mn:Fe ratio for eliminating harmful β-phase and obtaining microstructure with well distributed and fine intermetallics. 300 ppm Sr was added to the Mn-modified composite to investigate the effect of Sr and Mn on the microstructure and tensile properties of A356–10% SiC.AleksandarVencla et al. [10] studied Particulate composites with A356 aluminium alloy as a matrix were produced by compocasting process using ceramic particles (Al2O3, SiC) and graphite particles. The matrix alloy and the composites were thermally processed applying the T6 heat treatment regime. Structural, mechanical and tribological properties of heat treated matrix alloy and the composites were examined and compared. It was shown that heat treatment affected microstructure of the composites matrix. The fracture of the composites matrix was ductile, while transition from ductile to brittle fracture occurred in the zone of reinforcing particles. The values of elasticity modulus of all the composites were higher in relation to the matrix alloy. It was also established that wear resistance and coefficient of friction were better at the SiC particulate composites than at the Al2O3 particulate composite, while the addition of graphite particles improved tribological properties further. D. Sohrabi Baba Heidary et al. [11] studied settling of SiC particles in composite slurries of aluminum A356 alloy/SiC was investigated experimentally and the results were compared with theoretical predictions. The influence of size and volume fraction of SiC particles in different Al/SiC slurries together with thermal history during alloy solidification on the distribution of particles along the height of cylindrical composite samples was studied by image analysis of microstructures. In the theoretical part, the effect of particle shape, agglomeration of particles and hindered settling on the settling velocity of SiC particles was studied by using the Stokes equation with some relevant correction factors. Ali Mazahery et al. [12] studied the microstructure and mechanical properties of nano composites processed via stir casting. The composites were based on the A356 aluminum alloy reinforced with nanoSiC particles. The density measurements show that the samples contain little porosity and the amount of porosity in the composites increases with increasing volume fraction of SiC. The microstructures of the composites were examined using optical microscope and transmission electron microscope. Microscopic observations of the microstructures reveal that the dispersion of the particles is uniform. The yield strength, ultimate tensile strength and the elastic modulus are improved with the addition of nano particles although some reduction in ductility is observed. The highest yield strength and ultimate tensile strength are obtained with the addition of 3.5% SiCnano-particles. Yunhui Du et al. [13] studied the radial distribution of SiC particles in A356 liquid under the conditions of 25 deg. for gradient angle α of blade and 10 mm/s for speed of moving up and down of stirrer. The results show that there exists a nonlinear relationship between rotating speed of stirrer and radial relative deviation of SiCp content in A356 liquid between the center and the periphery of crucible. The greater the rotating speed of stirrer is, the bigger the radial relative deviation of SiCp content in A356 liquid becomes and the more nonhomogeneous the radial distribution of SiC particles in A356 liquid turns. In addition, when the rotating speed of stirrer is about 200 r/min, the vertical distribution of SiC particles in A356 liquid is relative uniform. S. P. Dwivedi [14] welded A356/C355 aluminium alloys by friction stir welding by controlling various welding parameters. A356 and C355 aluminium alloys materials have a set of mechanical and physical properties that are ideally suited for application in aerospace and automobile industries and not widely used because of its poor weldebility. To overcome this barrier, weldebility analysis of A356 and C355 aluminium alloys with high speed steel (Wc-Co) tool has been investgated. An attempt has been made to investigate the influence of the rotational speed of the tools, the axial force and welding speed on tensile strength of A356/C355 aluminium alloys joint. The experiments were conducted on a milling machine. The main focus of investigation is to determine good tensile strength. Response surface methodology (box Behnken design) is chosen to design the optimum welding parameters leading to maximum tensile strength. The result shows that axial force increases, tensile strength decreases. Whereas tool rotational speed and welding speed increase, tensile strength increases. Optimum values of axial force (3 /KN), tool rotational speed (900 RPM) and welding speed (75 mm/min.) during welding of A356/C355 aluminium alloys joint to maximize the tensile strength (Predicted 223.2 MPa) have been find out.

3. Comparison of various Aluminium alloys with A356 alloy

A356 alloy has very good mechanical strength, ductility, hardness, fatigue strength, pressure tightness, fluidity, and machinability. This alloy is used in many industrial applications such as airframe castings, machine parts, truck chassis parts, aircraft and missile components, and structural parts requiring high strength. Comparison of various Aluminium alloys with A356 alloy is shown in Table 1

Table 1: Comparison of various Aluminium alloys with A356 alloy

Alloy type		Temper	Tensile strength (MPa)	Yield strength (MPa)
ANSI	UNS			
201.0	A02010	T7	414	345
204.0	A02040	T4	310	193
242.0	A02420	O	159	N/A
		T61	221	138
A242.0	A12420	T75	200	N/A
295.0	A02950	T4	200	90
		T6	221	138
		T62	248	193
		T7	200	110
319.0	A03190	F	159	90
		T5	172	N/A
		T6	214	138
328.0	A03280	F	172	97
		T6	234	145
355.0	A03550	T6	221	138
		T51	172	124
		T71	207	152

C355.0	A33550	T6	248	172
356.0	A03560	F	131	66
		T6	207	138
		T7	214	N/A
		T51	159	110
		T71	172	124
A356.0	**A13560**	**T6**	**234**	**165**
		T61	**241**	**179**
443.0	A04430	F	117	48
B443.0	A24430	F	117	41
512.0	A05120	F	117	69
514.0	A05140	F	152	62
520.0	A05200	T4	290	152
535.0	A05350	F	241	124
705.0	A07050	T5	207	117
707.0	A07070	T7	255	207
710.0	A07100	T5	221	138
712.0	A07120	T5	234	172
713.0	A07130	T5	221	152
771.0	A07710	T5	290	262
		T51	221	186
		T52	248	207
		T6	290	241
		T71	331	310
850.0	A08500	T5	110	N/A
851.0	A08510	T5	117	N/A
852.0	A08520	T5	165	124

4. Processing of A356 alloy
4.1 Fabrication of A356 metal matrix composite
4.1.1 Electromagnetic stir casting

Electromagnetic stir casting set-up mainly consists a furnace and a stirring assembly (Fig. 1). In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix [8].

4.1.2 Mechanical stir casting
Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify. Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies. The Stir Casting set up is shown in Figure 2 [15].

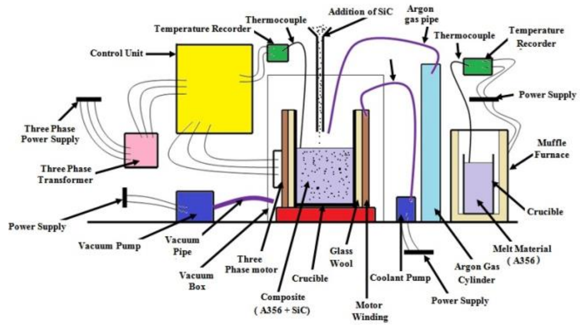

Fig. 1: Schematic view of electromagnetic stir casting set-up

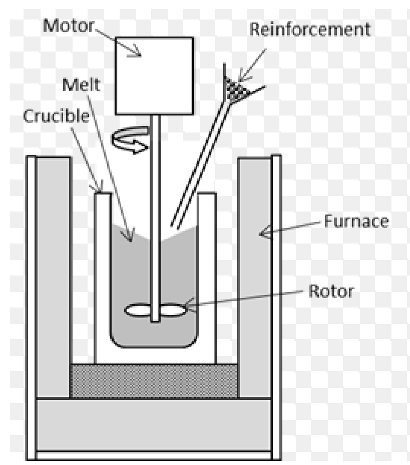

Figure 2: Schematic diagram of mechanical stir casting route

4.2 Heat Treatment

Heat treatment schedule plays a major role in achieving a desired microstructure and mechanical properties of A356 based metal matrix composite. In A356 alloys due to the wide range of solubility of Al in Mg, phase precipitates during its solidification and during ageing treatment which is responsible for appropriate mechanical properties [16].

5. Mechanical Properties

Properties of A356 based metal matrix composite are depended on its microstructure, grain size, volume and size of second phase etc. Porosity and interdendritic shrinkage are also play a major role to determine the mechanical properties of the alloy. The mechanical properties are also sensitive to temperature, strain rate and other test conditions.

5.1 Effect of temperature and strain rate

Size of second phase, in A356 based metal matrix composite, is responsible for room temperature strengthening effect. This intermetallic has low melting point and has a propensity to develop into coarsen at elevated temperature and no longer act as a barrier for dislocations. As a result, in A358 based metal matrix composite this phase shows the way to the poor prominent temperature properties. It should be renowned that temperature has a huge effect on the tensile properties at lower strain rate whereas at higher strain rate, the temperature effect is less significant [17].

5.2 Effect of grain size

Mechanical properties are extremely reliant on grain size. The yield strength can be related with grain size by well-known Hall-Petch equation [18];

$$\sigma = \sigma o + Kd^{-1/2} \quad (1)$$

Where σo is the yield stress of a single crystal, K is a constant and d is the grain size and σ is the yield stress. With growing the Taylor factor the value of K increases. Both strength and ductility are improved with reduction in grain size. By thermo- mechanical treatment and severe plastic deformation the higher strength and ductility are obtained. This is owing to the fact that these processes provide fine grain size. It is watched that intergranular fracture is observed in alloy with a large grain size: however, intergranular fracture is limited in A356 based metal matrix composite with a small grain size, representing that the fracture mechanism is changed by grain refinement. This is for the reason that the critical stress for crack propagation at grain boundaries increases with decreasing grain size.

5.3 Porosity and specific strength

Porosity (P) is the percentage of the pores volume to the total volume with the volume of a substance. It is defined by [19]:

$$P = \left(1 - \frac{V_{Theoretical}}{V_{Experimental}}\right) \times 100\,\% \quad \text{Or,} \quad P = \left(1 - \frac{\rho_{Experimental}}{\rho_{Theoretical}}\right) \times 100\,\% \qquad (2)$$

Where, P = Porosity
V = Volume
ρ = Density

Porosity and characteristics of pores (including size, connectivity, distribution, etc.) affect the properties of materials greatly. Generally, for the same material, the lower the porosity is, the less the connected pores are. Thus the strength will be higher, the water absorption will be smaller, and the permeability and frost resistance will be better, but the thermal conductivity will be greater. The density measurements were carried out to determine the porosity levels of the samples. This was achieved by comparing the experimental and theoretical densities of each volume percent SiC reinforced composite. The experimental density of the samples was evaluated by weighing the test samples. The measured weight in each case was divided by the volume of respective samples. The theoretical density was evaluated by using the rule of mixtures given by:

$$\rho_{A356/SiC_p} = Vol._{A356} \times \rho_{A356} + Vol._{SiC} \times \rho_{SiC} \qquad (3)$$

Where,

ρ_{A356/SiC_p} = Density of Composite

5.4 Wear behavior

Wear of metals is almost certainly the most important yet smallest amount understands feature of tribology. Friction and wear are not the intrinsic material properties. They are reliant on both the working conditions and the properties of materials. Broadly varied wearing conditions reason wear of materials by various mechanisms. Small changes of load, speed, frictional temperature or properties of materials together with microstructures reason extraordinary changes in the wear of contact surfaces [20]. Wear properties are significant particularly when A356 based metal matrix composites are to be applied for critical automobile and aircraft applications. There are a number of mechanisms of wear, which take in seizure, melting, oxidation, adhesion, abrasion, delamination, fatigue, frettling, corrosion, and erosion. Wear may usually be abridged by using a lubricant with appropriate anti-wear additives or changing the materials and/or the operation parameters affecting the wear rate [21, 22].

6. Applications

A356 based metal matrix composites utilized widely in aircraft engines, air frames and landing wheels. A356 alloys are usually used for aircraft applications due to their improved corrosion and creep resistance. High specific strength and rigidity coupled with ease of fabrication are important for missile and space applications. Automobile industries are the latest beneficiary of A356 alloy, currently exploring its maximum usage. Typical uses, aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water-cooled cylinder blocks. Other applications, where excellent castability and good weldability, pressure tightness, and good resistance to corrosion are required, aircraft structures and engine controls, nuclear energy installations, and other applications where high-strength permanent mold or investment castings are required.

Conclusion

In spite of several advantages and applications of A356 based metal matrix composites, there are some limitations which confine its full utilization for industry applications. Some of the challenges that are facing A356 alloy in order for its extensive acceptance for industrial applications.

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