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RESEARCH

The Structure and Mechanical Properties of an Aluminium A356 Alloy Base Composite With Al_2O_3 Particle Additions

Composites-castings with an aluminium A356 alloy base and additions of 1, 2, and 3 % (wt.) of Al_2O_3 reinforcement of 12μm size were made. A side by side investigation of the microstructure and hardness of the composite and the base alloy cast into a steel mould was done. According to hardness values samples of A356 + 3 % Al_2O_3 composite with a particle size of 12μm were selected. These samples were additionally pressed in a special tooling by which tensile test samples were obtained. Application of the compocasting process led to a transformation of a dendritic to a nondendritic structure of the base alloy. The mechanical properties of the composite are improved in relation to the base alloy.

Keywords: A356 alloy; composites; compocasting

INTRODUCTION

A356 belongs to a group of hypo eutectic Al-Si alloys and has a wide field of application in the automotive and avionics industries. It is used in the heat treated condition in which a optimal ratio of physical and mechanical properties is obtained [1]. The alloy solidifies in a broad temperature interval (43 ºC) and is amenable to treatment in the semi solid state as well as casting [2,3]. For this reason it is the subject of rheological investigations [4], as well as methods of treatment in the semi solid state [3,5]. By these methods it is possible to obtain castings with reduced porosity of a non dendritic structure and with good mechanical properties. Besides this the A356 alloy is used as a matrix for obtaining composites [6], which have an enhanced wear resistance, favourable mechanical properties at room temperature and enhanced mechanical properties at elevated temperatures.

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A356 solidifies in a wide enough temperature interval between the solidus and liquidus temperatures that it can be used as a matrix for obtaining composites by the compocasting method. In this work for obtaining a composite unmodified A356 alloy was used so as to evaluate the effect of added particle strengthener on the structure and mechanical properties of the composite without modification effects. The results of preliminary mechanical tests on the obtained composite were compared with the known values of mechanical properties of a commercial modified heat treated A356 alloy [8].

EXPERIMENTAL

For this experiment an A356 alloy of the chemical composition shown in Table1 was used.

Before making the composite an A356 cylinder of 12 mm diameter and 100 mm height was cast into a cold graphite mould out of which samples for metallographic examinations and hardness measurement were made. The composites were made by the compocasting method using mechanical mixing of the matrix i.e. the A356 alloy which was previously bought into the semi solid state and addition (infiltration and admixing) of particles of the strengtheners. Addition of Al_2O_3 powder particles of a average size of 12 μm was done in quantities of 1, 2 and 3 wt. % respectively.

Table 1. Chemical composition of A356

Element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Wt. (%)	7.20	0.02	0.29	0.01	0.18	0.01	0.02	0.11	Balance

The apparatus for the compocasting method is shown in Fig. 1. It is made up of a laboratory electric resistive 2 kW furnace (with additional temperature control equipment) and a mixer. The crucible inside the furnace was made by a special procedure out of alumina and has an opening in the wall for introducing a thermocouple to 20 mm from the bottom of the crucible. It was possible to record and change the number of revolutions of the mixers shaft (Fig.1). The active part of the mixer is platelike whilst the ratio of the circle which the mixer traces to the inner diameter of the crucible is 0.53.

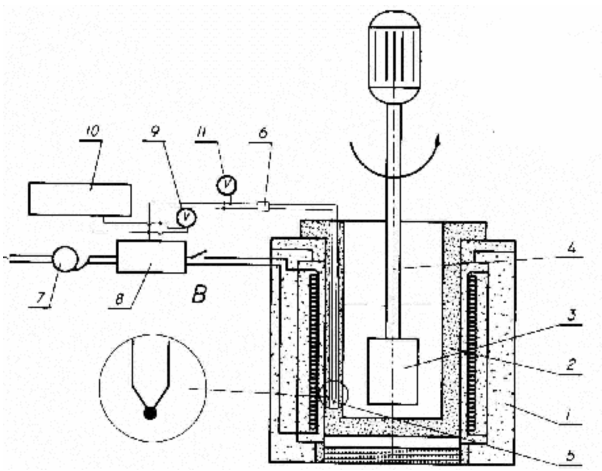

Fig. 1. Apparatus (1), Resistive furnace (2), Crucible (3), Mixer (5), Thermo couple (6 to 11) and Measurement and regulation

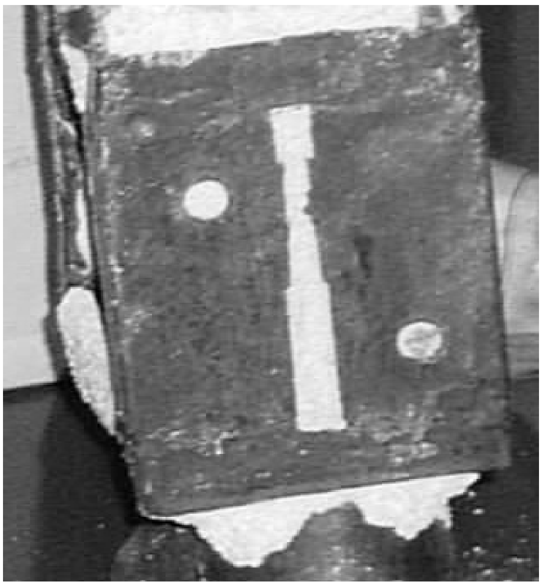

Fig. 2. Tooling for pressing the composite

The experimental work irrespective of the amount of added strengthener particles encompassed preparation of the melt, infiltration of stengthener particles and mixing of the semi solid melt with the infiltrated stengthener particles. The preparation of the melt was done by heating and melting of the melt (A356 alloy), overheating of the melt to 650 ºC (30º above the liquidus temperature) for cleaning the slag and cooling to 605 ºC (26 wt. % of solid phase).Then a mixer was introduced into the semi solid melt and mixing was done with a speed less than the one proscribed. With uninterrupted mixing the semi solid melt was heated to a temperature of 600 ºC (33 wt. % of solid phase), i.e. to the working temperature. The mixing intensity was then increased to the planed rpm of the mixer (500 rpm) after which a premixing of the semi solid melt for 5 minutes was done with a goal of breaking up the dendrites. Infiltration of the powder was done in a 5 to 7 minute period depending upon the quantity of particles. After infiltration an additional mixing was done with 30 minute duration to enhance the strengthener particle distribution. Afterwards the semi solid melt of the composite was poured into a prepared heated (500 ºC) steel mould where manual pressing was done until metal drops appeared at the mould joints. Cylindrical castings-rods were obtained, of 36 mm diameter and 150 mm height from which test samples for metallographic investigation and hardness measurements were machined. Test samples for tensile testing and tribological examinations were obtained by additional pressing. A special tooling made out of IN100 shown in Fig. 2 was used.

A characterization of the obtained composite samples included metallographic examination, measurement of hardness and preliminary tensile testing.

Heat treatment of a small number of composite samples according to the treatment proscribed for the commercial A356 alloy was done. This treatment encompasses a solution anneal for 6 hours, quenching in water followed by artificial ageing for 6 hours and air cooling. This procedure was used as a test just to evaluate the values of the basic mechanical indicators (without additional metallographic characterization of the samples).

RESULTS

Fig. 3 (magnification 200 x) shows the results of the metallographic investigation. The structure of base unmodified alloy is dendritic (Fig. 3a). Under the influence of the shear forces caused by the rotation of the mixer a transformation of dendritic to a non dendritic structure of the primary α phase particles took place. Large elliptically shaped primary particles are formed (Figs. 3b, 3c and 3d) and a coarsenining of the structure is obvious. An overview of the morphologies in Figs. 3b, 3c and 3d shows that the strengthener particles are not only placed in the in the eutectic zone but are infiltrated in the primary particles as well. The hardness measurement results are shown in table 2. The values for the hardness of composites with 1 and 2 wt. % particle strengthener differ only a little while a significant increase in hardness is observed with a 3 wt. % particle strengthener. If values of hardness of the composite are compared to the values of hardness for the sample made from the cylinder cast into the graphite mould (72 HV) it is observed that only the value of the hardness of the composite with 3 wt. % Al_2O_3 exceeded this value. Also an additional increase in hardness after heat treatment was observed.

Table 2. Hardness of composite materials

Composite (A356)	1 % Al_2O_3	2 % Al_2O_3	3 % Al_2O_3	3 % Al_2O_3, H.T.
Hardness ($HV_{50\ gr}$)	62.4	62.9	72.5	78.8

Chosen samples of the composite with 3 wt. % Al_2O_3 were subjected to preliminary tensile testing. The average value of tensile strength of composite samples is 190 MPa, while for the heat treated samples it is 211 MPa.

DISCUSSION

The solidification of alloy A356 according to the equilibrium phase diagram [2] commences at 620 ºC by the separation of aluminium rich primary α phase. At 577 ºC an eutectic transformation takes place when the rest of the melt solidifies into a two phase eutectic mixture. At the end of solidification the structure of the A356 alloy consists of primary particles of α phase and a eutectic in the space between the particles. The size and the shape of the separated silicon particles determine the morphology of the eutectic which has a great effect on the mechanical properties of the alloy. The appearance of the eutectic primarily depends upon the cooling rate and impurities present in the alloy.

a)
b)
c)
d)

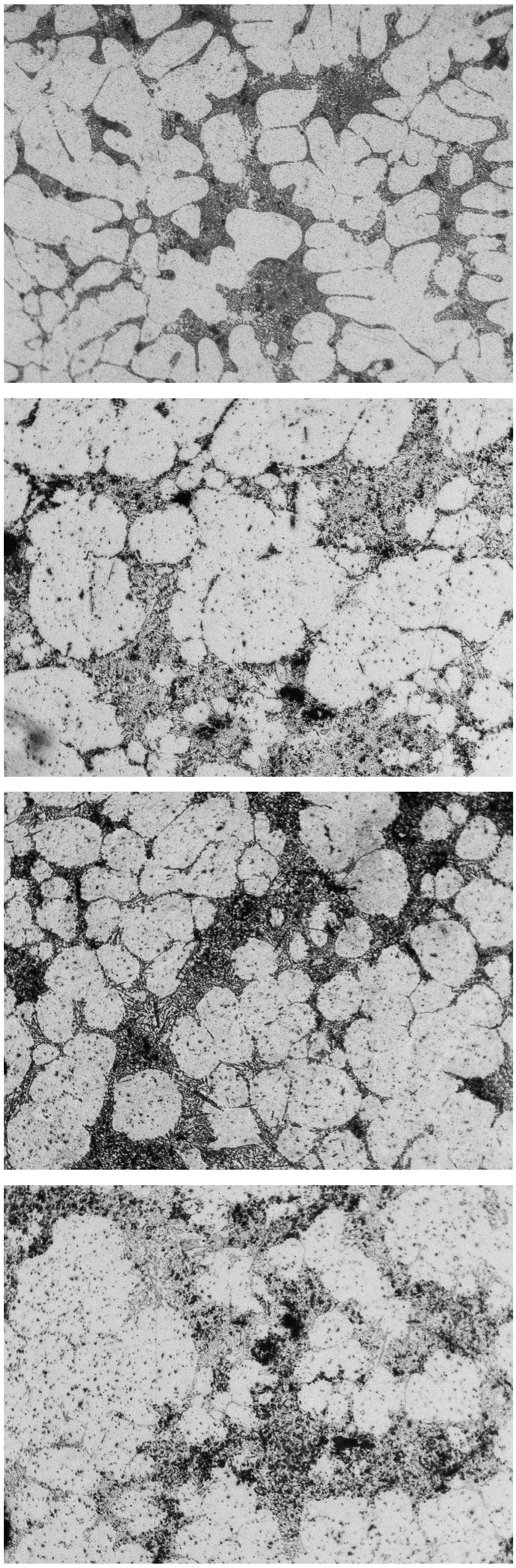

Fig. 3. Microstructure of A356 and a composite based on it: a) A356 cast into a graphite mould, b), c) and d) Composite A356 + 1, 2 and 3 wt. % Al_2O_3 (12 µ particle size)

When casting with high cooling rates of the melt the structure of A356 alloy consists of primary particles of a dendritic shape with a eutectic in the interdendritic space with rodlike silicon particles [7]. The structure shown in Fig. 3a for the sample made from the cylinder cast into a cold graphite mould complies with this above mentioned structure. Nondendritic structures (Figs. 3b, 3c and 3d) obtained as a result of the mixing during the compocasting procedure lead to the fact that under the previously described experimental conditions a transformation from a dendritic to a nondendritic structure took place. With lower and middle mixing speeds which are used for the compcasting procedure (with infiltration of the particle strengthener) it is not possible to obtain the desired fineness of the structure as opposed to fine elliptic-circular particles which it is possible to obtain at high mixing speeds by applying the popular thixocasting procedure (without strengthener). I.e. at great mixing speeds under the effect of centrifugal force particles of strengthener concentrate along the peripheral parts of the casting, segregations at a macro level form and the distribution of the strengthener is uneven. Because of the requirement for an even distribution of the strengthener trough the whole volume of the composite with a fine structure at the same time, the design of the morphology of composite structures using the compocasting procedure represents a formidable research task. Infiltration of strengthener particles into the space of primary particles (Figs. 3b, 3c and 3d) which appear under the liquidus temperature and during mixing are present with nearly 40 wt. % is obviously the result of collisions (interactions) of primary particle-stengthener particle. The other part of the strengthener particles is placed in the eutectic zone, so that it is made up of mixed particles of strengthener (Al_2O_3) and Si particles in an Al rich α-phase matrix.

In the composite with 1 and 2 wt. % Al_2O_3 the primary particles are about the same size in the shape of statistically distributed aggregates separated by a narrow eutectic zone. In the case of the composite with 3 wt. % Al_2O_3 a further agglomeration is noticed which indicates an excess mixing time. This fact can be used in further work to optimize the mixing process parameters. A comparison of the results of mechanical testing (i.e. a hardness value of 72.5HV and tensile strength of 190 MPa) with the values for modified heat treated aluminium alloys with lower magnesium content [8] shows that the mechanical properties of the obtained composites are comparable to the values for modified heat treated Al-Si alloys of appropriate composition. This gives encouragement for further work in both the making of composites with a greater content of strengthener as well as in the improvement of the properties of the obtained composites by heat treatment. The values of the mechanical properties of heat treated composite samples (hardness of 78.8 HV and tensile strength of 211 MPa) indicate a certain improvement but are lower than expected. It is possible that the applied heat treatment used for commercial castings of A356 led to over ageing of the sample. It is known that strengthener particles accelerate the ageing process [9] so it is necessary to further investigate this effect and modify the heat treatment.

CONCLUSION

Based on the previous it can be concluded that:

Composite castings with an A356 alloy matrix with additions of Al_2O_3 particles with a size of 12 μm have been made.

By the compocasting method a non dendritic microstructure with elliptical primary particles has been made.

A favourable distribution of strengthener particles in the matrix has been achieved.

A favourable combination of mechanical properties in the composites is obtained in this phase of work.

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