

Aluminium dross AIMCs

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MEMORIE

In this work, the potential of finely powdered aluminum dross by-product with an average particle size of 67 μm as a cost effective reinforcement in discontinuously reinforced aluminum matrix composites (A356) was demonstrated. Using a standard rheocasting procedure, samples of composite material were obtained consisting of 20 vol. % of one as-received and three laboratory processed grades of dross particles with which differed mainly in particle size and the level of impurities.

Inspection of the tensile properties of these different composite materials showed that a slight improvement in strength over the unreinforced matrix is achievable only by the introduction of fine dross particles with a particle size less than 10 μm , while in composites with larger dross particles no strengthening effect observed. In contrast, evaluation of the wear properties demonstrated that the introduction of coarse and even as-received dross particles in an aluminum matrix results in a significant improvement in the wear resistance of the composite material.

1.0 INTRODUCTION

The objective of this work was to investigate the strengthening potential of fine aluminum dross particles as a cost effective reinforcing phase in aluminum-based MMCs. The raw material was provided by the firm IMPOL d.d in Slovenska Bistrica, Slovenia, in the form of a cyclone fraction of fine aluminum dross particles with an average particle size of 67 μm .

The as-received powder was treated with boiling water in order to remove all water soluble impurities and also milled in a ball mill. Finally, by appropriate vacuum filtration, different fractions of aluminum dross particles were prepared and used as the reinforcement.

In previous work [1], the as-received cyclone fraction of aluminum dross particles was used directly for the preparation of MMCs by conventional squeeze casting and the pressure infiltration technique. Preliminary results indicated the absence of a strengthening effect in the resulting composite, probably due to debonding at the interface between the dross particles and the alloy matrix, as well as the presence of porosity in aluminum dross clusters. Thus, the purpose of this work was to clarify if a cost-effective purification of the aluminum dross particles combined with non-intensive milling could result in a valuable improvement in the yield strength of the composite material.

2.0 METHODS

Examination of the aluminum dross particles involved standard chemical analysis, optical microscopy and analysis of the particle size distribution.

The as-received aluminum dross particles were treated in boiling water for 1 hour with constant stirring in order to remove all the water soluble impurities and then carefully washed with cool water. The water slurry of the non-soluble fraction of particles was further processed by milling in a planetary ball-mill for 1 hour.

The next step involved vacuum filtration of the aluminum dross powder, performed using 20 μm and 10 μm membrane filters. In this way, three fractions were prepared: fraction A consisting of particles with size less than 10 μm , fraction B

consisting of particles with size between 10 and 20 μm and fraction C consisting of particles with size over 20 μm .

The aluminum dross MMCs were prepared by a conventional rheocasting technique. The equipment used in this work is illustrated in Fig. 1. The apparatus consisted of a mullite crucible placed inside a resistance heated vertical muffle furnace having a bottom pouring arrangement. The bottom hole of the crucible (12 mm \varnothing) was plugged with a graphite stopper. The mixing assembly consisted of a DC variable speed motor, the spindle and the dispersion impeller having blades angled to about 45° from a line perpendicular to the shaft. The use of a specially designed impeller having angled blades provided a shearing and wiping action which effectively homogenized the mixture of molten aluminum alloy and particulate material. The impeller was machined from stainless steel and then coated with Armeco 552 ceramic adhesive to avoid contaminating the melt or damage to the stirrer. The crucible was provided with a protective cover and an inert gas or technical vacuum protection chamber.

Approximately 2 kg of the A356 alloy were melted in the crucible for each experiment and then heated to 10 K above its liquidus temperature. After that the stirrer was immersed into the melt and placed in a lower position.

The furnace temperature was progressively diminished according to a programmed cooling regime (about 1 K/min.) to the temperature in the solidification range of the alloy under vigorous stirring (500 rpm).

At the same time, the aluminum dross particles were preheated to 723 K for 1 hour before being added to the crucible. As the melt reached the operating temperature, the preheated aluminum dross particles were added near the top of the mushy alloy using the refractory baffle and argon as a carrier gas. The baffle was immersed 5 mm below the surface of the mushy alloy with a tilt angle of about 45° to the direction of flow. The average feeding rate was 0.2-0.6 kg per hour.

Once the aluminum dross particles were completely added, isothermal agitation of the melt was maintained for 20 minutes to obtain a uniform distribution of the reinforcement through the matrix.

After that the crucible was quickly extracted from the furnace and the composite matrix was rapidly solidified in an intensive flow of cool air in order to retain the globular microstructure.

Cylindrical composite ingots of 70 mm diameter and 100 mm long were obtained.

Volume percentage of dross particles in the matrix

The volume percentage of dross particles in specimens was

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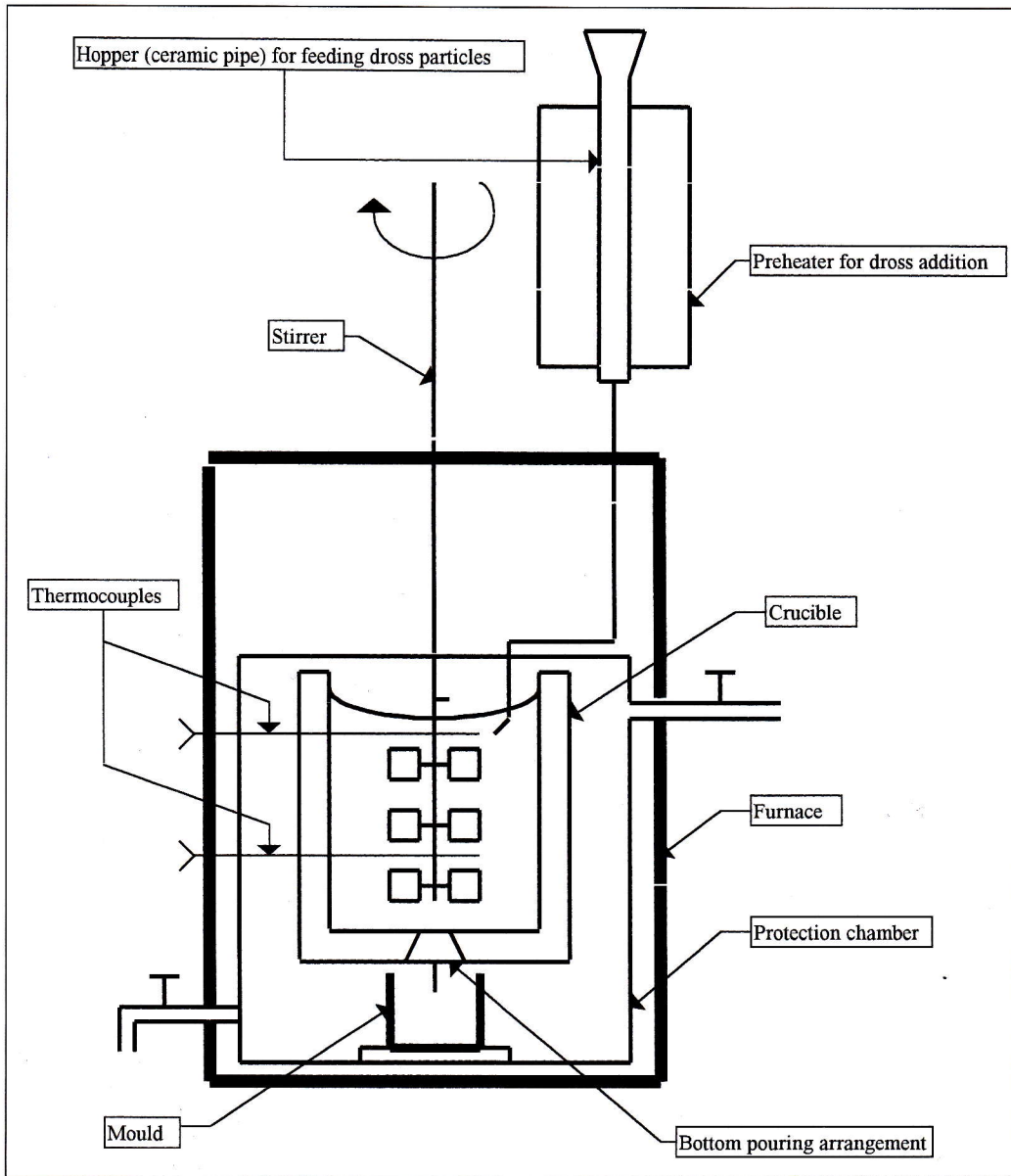


Fig. 1: Experimental arrangement used for rheocasting.

measured on polished samples by a LECO 2001 Image Analyzer. Three pictures were quantitatively analyzed for each sample.

Tensile specimens of gauge length 70 mm and cross section of 6x2 mm were machined from thin plates. Tensile tests were conducted on five samples for each value using an Instron testing machine and a 10 mm extensometer.

Preliminary dry sliding wear testing of squeeze cast and of some gas pressure infiltrated specimens against an SAE 52100 steel counterface was carried out using a pin-on-disc wear testing machine with a sliding speed of 1.0 m.s⁻¹ and an applied contact load of 60 N. Wear rates were calculated using the relationship:

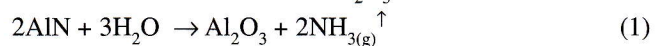
$$\text{Wear Rate} = \text{Volume of Wear (mm}^3\text{)} / \text{Sliding Distance (m)}$$

To start the test, the sample was lowered by the operator onto the already rotating disc; contact was maintained for 2000 seconds.

3.0 RESULTS AND DISCUSSION

The chemical composition of aluminum dross particles before and after purification is compared in Table I. As evident, after purification the main constituent in the final product is aluminum oxide.

This is because aluminum nitride, next in importance to aluminum oxide in the as-received product, hydrolyzed during the heat treatment in water to Al₂O₃:



Note that in order to prevent the liberation of gaseous ammonia during the hydrolysis of AlN, it is more convenient to use an aqueous solution of HCl.

The particle size distributions in as-received and in milled aluminum dross powders are compared in Fig. 2. The particle size distributions measured in grades A, B and C of aluminum dross particles separated by vacuum filtration after appropriate milling are plotted in Fig.3. The results indicate that most of the coarse agglomerates and aggregates detected in as-received aluminum dross powder were successfully broken down by the milling treatment applied. In fraction C, consisting of aluminum dross particles coarser than 20 μm, all existing aggregates and agglomerates are less than 50 μm.

In Fig. 4 the microstructure of MMC reinforced with 20 vol. % of grade A aluminum dross particles is shown. It is evident that the reinforcing particles are more or less uniformly dispersed in matrix.

However, the introduction of fine dross particles by rheocasting is difficult. Thus, in order to obtain samples reinforced with 20 vol. % of fine dross particles (grade A) for tensile te-

	As-received (wt %)	After purification (wt %)
Al ₂ O ₃	78.24	94.74
SiO ₂	1.46	1.56
Na ₂ O	6.28	0.03
CaO	0.47	0.03
TiO ₂	0.13	0.13
MgO	1.97	0.03
K ₂ O	1.47	0.03
Zn	0.05	0.53
Cu	0.51	0.55
Mn	0.03	0.03
Fe	1.00	1.07
Al _{metallic}	1.16	1.24
AlN	7.23	0.03

Table 1: Chemical composition of aluminum dross.

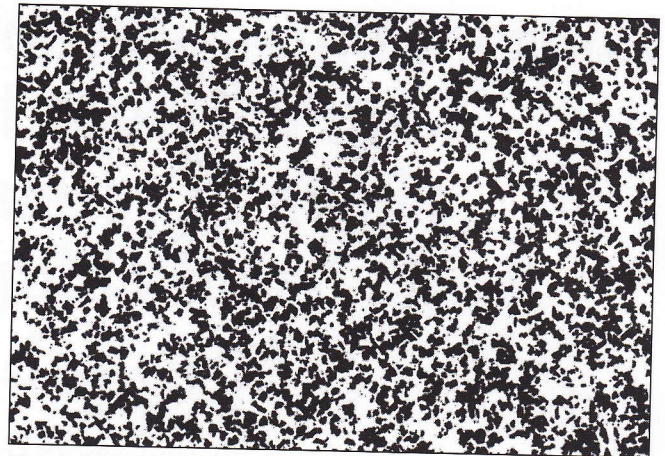


Fig. 4: Microstructure in composite reinforced with 20 vol. % of grade A dross particles. Magnitude: 100x

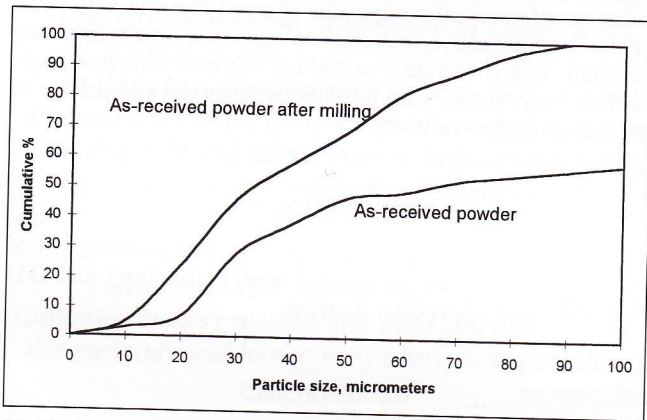


Fig. 2: Comparison in particle size distribution between as-received and milled species of aluminum dross.

Composite	YS (MPa)	UTS (MPa)	Elongation (%)	Elastic modulus (Gpa)
A356 (T6) unreinforced	205	280	6	76
356/as-received dross (T6)	158	214	3	82
356/as-received purified dross (T6)	167	219	3	83
356/dross grade A (T6)	218	291	3.5	89
356/dross grade B (T6)	189	267	3	83
356/dross grade C (T6)	163	221	2.9	79

Table 2: Tensile properties of Al-based composites reinforced with 20 vol. % of aluminum dross particles.

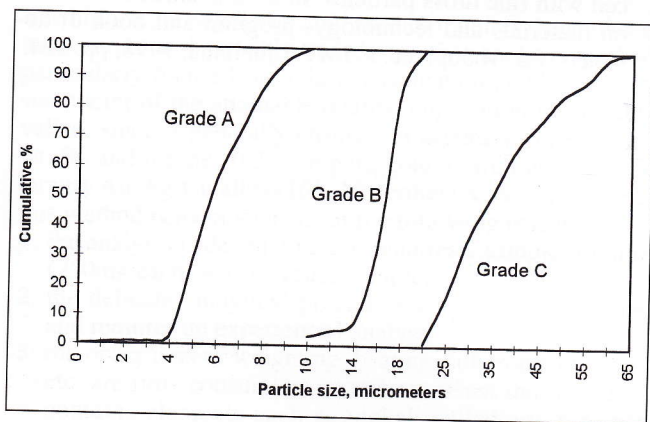


Fig. 3: Particle size distribution in different grades of aluminum dross after milling and vacuum filtration.

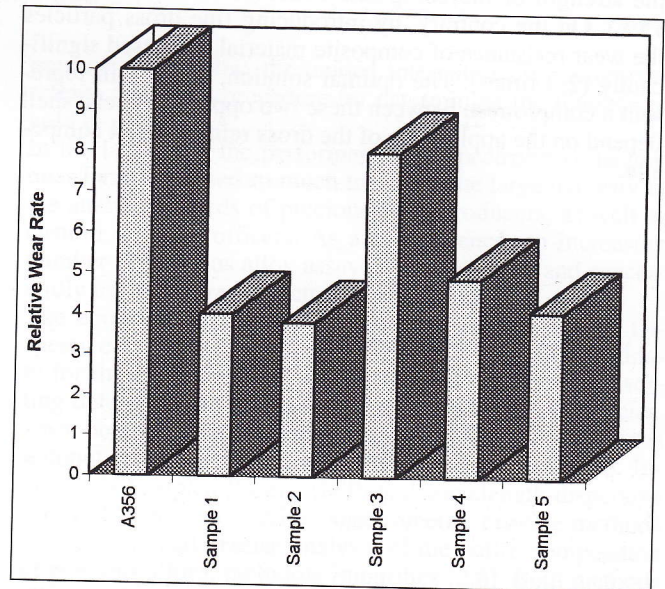


Fig. 5: Relative wear rate for unreinforced A356 and the different composite materials considered in this work.

sts, an accurate control of stirring action was performed continuously.

Preliminary tensile tests were carried out to investigate possible improvement of tensile properties of the composite samples in comparison with the non-reinforced matrix alloy. Table 2 lists the preliminary results obtained. A small improvement in strength over the unreinforced alloy occurred only in the composite reinforced with 20 vol. % of fraction A of aluminum dross particles.

Generally, the performed tensile tests demonstrated that the introduction of fine dross particles (grade A) resulted in an MMC with ~15 % higher strength in comparison with the counterpart containing as-received dross.

The preliminary dry sliding wear rate of non-reinforced matrix alloy and MMCs reinforced with as-received and laboratory prepared grades A, B and C of dross particles against an SAE 52100 steel counterface is shown in Fig.5. As expected, the addition of dross particles to the aluminum alloy significantly increased its wear resistance. Based on the collected results, all of the composites exhibited improved wear resistance with increasing particulate diameter. Superior wear resistance was obtained using coarse as-received dross particles which in the same time decrease significantly the strength of composite material. The situation is explained in Fig.6 where the relative wear rate and the yield strength of the composite material are plotted as a function of the size

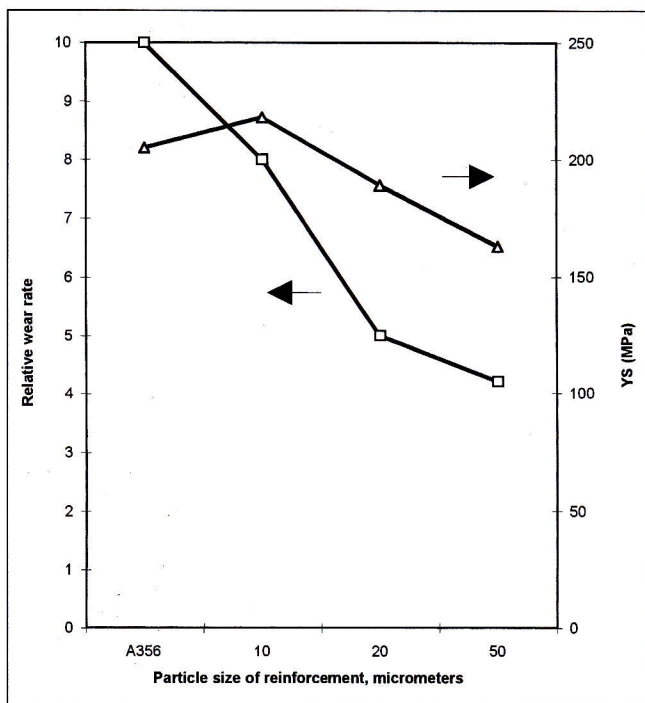


Fig. 6: Influence of the size of aluminum dross particles on the measured relative wear rate and the yield strength of the composite material.

of the aluminum dross particles. As evident, by lowering the size of the aluminum dross particles a small improvement in the strength of the composite could be achieved (approx. 15%). On the contrary, by introducing fine dross particles the wear resistance of composite material decreased significantly (2-3 times). The optimal solution, which will represent a compromise between these two opposite effects, shall depend on the application of the dross reinforced Al composite.

4.0 CONCLUSION

The cyclone fraction of aluminum dross particles, which is a common waste by-product in aluminum smelters, seems to be a promising reinforcing phase for cost-effective and environmentally safe discontinuously reinforced aluminum based composites.

By applying a convenient rheocasting process, composites with 20 vol. % of reinforcing phase can be obtained.

At a constant volume fraction of reinforcing phase, the tensile properties and wear resistance of the composite material are affected by the size of the aluminum dross particles. Introduction of fine dross particles with a particle size less than 10 μm results in a small improvement in strength of the composite over the unreinforced alloy. In contrast, the use of as-received coarse dross particle provides superior wear resistance. However, in that case, there is, of course, some sacrifice in strength.

Preliminary inspection of the tensile properties and wear behavior of selected composites showed that the new composite is an attractive material for tribocomponents and may be applicable for some less critical but cost effective engineered components, with possible widespread application in the transportation industry.

5.0 ACKNOWLEDGMENTS

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6.0 REFERENCES

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ABSTRACT

COMPOSITI A MATRICE DI ALLUMINIO OTTENUTI CON ALLUMINIO DI RECUPERO

Nel presente articolo vengono descritte e dimostrate le potenzialità, in termini di risparmio economico, di un sottoprodotto ottenuto con alluminio di recupero ridotto in polvere fine, con grani di dimensioni di 67 μm, impiegato come rinforzo in compositi a matrice di alluminio (A356) rinforzati in modo discontinuo.

Mediante un procedimento standard di "reocasting" sono stati ottenuti campioni di materiali compositi con il 20% in volume di particolari "as received" e tre classi di particelle di recupero ottenute in laboratorio le quali differivano so-

prattutto in termini di dimensioni delle particelle e di tensionali livello di impurezze.

La determinazione delle caratteristiche tensionali dei diversi materiali compositi ha mostrato che un leggero miglioramento della resistenza rispetto alla matrice non rinforzata è ottenibile solo mediante l'introduzione di particelle aventi una dimensione inferiore a 10 μm, mentre non è stato osservato alcun effetto di rinforzo nei compositi ottenuti con particelle di recupero di maggiori dimensioni.

Invece, l'analisi sulla resistenza all'usura ha dimostrato che l'introduzione in una matrice di alluminio delle particelle di recupero ha come risultato un significativo miglioramento della resistenza all'usura del materiale composito.