EFFECT OF MULTIPLE REMELTING ON SELECTED PROPERTIES OF DISPERSED REINFORCED ALUMINUM MATRIX COMPOSITE

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Abstract

In the investigations, described in the paper, the analysis of conditions for recycling materials used in car vehicles is presented. This problem is related with the requirement of UE regarding recovery of product, material or energy - (the Instruction EU No. 2000/53/WE, 18.09.2000). This research is aimed on the investigation of the recycling treatment on properties of commercial aluminum matrix composite reinforced with SiC particles, as a candidate for prototype production of modern brake discs and rotors for automotive applications.Repeated remelting of F3S.10S composite (A359 aluminum alloy reinforced with 10% by vol. of SiC particulates) has been performed. Multiple remelting of composite followed by its gravity casting to the cast iron die does not cause any important changes in composite microstructure noticeable under optical microscopy magnifications. The results of investigation of physical and mechanical properties show that recycling treatment, characterized by the number of remelts followed by the same casting procedure, causes the noticeable change of all properties of composite material.The results demonstrate a continuous decrease in utility properties of composite material with increase of the number of remelting operations, showing tolerable reduced strength characteristics after 9^{th} remelting. Nevertheless, in the face of occasional increase in a given property from one remelt to another, these preliminary investigations suggest the possibility to improve recycling process by proper selection of liquid metal treatment and subsequent casting procedure.

Keywords: *transport, recycling, aluminium matrix composite, remelting*

1. Introduction

The development of present production techniques results in increase of ready products, which after the end of the technical exploitation demand their recycling or storage. One of more arduous groups of products determines car vehicles withdrawn from the exploitation. Together with the increase of the quantity of used up cars the interest in recycling problems occurs because more than once this process determines not only the guarantee of the environment protection, but simultaneously the possibility of gaining over of valuable secondary raw materials. Introduced again to the technological circulation they can be the source of materials about similar functional properties as the original material.

From the materials engineering point of view, aluminum matrix composites are the group of advanced materials, which can be applied in the automotive industry [1-3] because of their light-weight, low-cost and very attractive functional properties. However, the problem of the recycling is still open and should be solved in order to introduce metal matrix composites (MMCs) to wide-scale production. The simple, univocal selection of used composite element for brake assembly allows producers to recycle material and use it for secondary parts production through multi-remelting.

This research is focused on the investigation of the effect recycling treatment (after first and up to ninth remelting) on selected properties (electrical conductivity, density, hardness, tensile characteristics and microstructure) of commercial F3S.10S aluminum matrix composite reinforced with SiC particles, as a candidate for prototype production of modern brake discs and rotors for automotive applications.

2. Experimental procedure

Al-matrix composite of F3S.10S type (A359 alloy reinforced with 10 vol. % SiC particles) was produced in the form of ingots by Duralcan (Canada). Chemical composition of the A359 matrix, as given by producer, is shown in Tab. 1.

Tab. 1 Chemical composition of metal matrix in F3S.10S composite

Chemical composition, wt %							
Material grade	Si	Fe	Cu	Mn	Mg	Zn	Ti
F3S.10S	8.88	0.07	0.001	0.002	0.62	0.002	0.10

Samples for investigations have been obtained by gravity casting to the cast iron die, sinking the batch in the crucible furnace of the type TS-THE FAG END-96/501. Thermocouple AOT-2 NiCr-NiAl was used to measure the temperature of liquid metal. The composite ingots were melt and preheated up to 720°C. Before casting, the temperature of die measured with the contact-thermocouple THERM 2120 was within the range from 180°C to 200°C.

The simulation of the recycling process of the ready product was carried out by melting of an original material and its casting of the first sample group. The rest of liquid metal was cast in the die again. After the solidification, the material was remelted in order to cast the second sample group and the remaining liquid metal was again cast in the form of ingots. This process was repeated 9-times receiving samples (simulating the ready product) successively after 1, 2 until 9-times repeated remelting of the original material (i.e., total number of melting processes was 9).

The X-ray examination was carried out according with requirements of the PN-EN 12681/ASTHMAS-E 446/186 standard accepting the level of the acceptance agreeable with ASTHMAS-E 505 (severity level 1) in order to eliminate the castings that do not fulfill the qualitative requirements.

The investigation of the electrical conductivity was carried out on the cast surface by means of SIGMASCOPE SMP10 instrument, which measures the electrical conductivity using the method of eddy currents. This method was selected taking into account high sensitivity of electrical conductivity to even small changes in the materials structure and chemistry, that quite often are not recordable by other conventional techniques. An aim of this investigation was to check the possibility of the identification of successive recasting, and consequently the qualification if the product is cast from the material after the recycling and eventually whereby.

In order to determine any possible increase of the degree of poisoning with gas after successive composite recasts, the density of composite was determined by Archimedes method using AT200 METTLER Toledo analytical balance on the specimens cut from the bottom part of each casting.

The measurements of the hardness HBW 5/250 were carried out according with standard PN-EN ISO 6506-1:2002, using HPO-250 device. The ball of 5 mm diameter, made from sintered carbide, was used to apply a load force of 2.452 kN for 10-15 s on the cross-section surface of the bottom part of each casting.

Investigations of mechanical properties were performed on tensile test samples of 5 mm diameter according to the PN-EN 10002-1:2004 standard by means of INSTRON 8874 machine.

Additionally, the comparative structural examination of F3S.10S composite after 1^{st} and 9^{th} remeltings was done on the cross-sectioned samples after tests of mechanical properties. Metallographic investigations were performed by means of OLYMPUS PMG3 optical microscope at magnifications up to 1000×.

3. Results and discussion

The results of investigation of physical (Fig. 1-2) and mechanical (Fig. 3-5 and Tab. 2) properties show that recycling treatment, characterized by the number of remelts followed by the same casting procedure, causes the noticeable change of all properties of composite material.

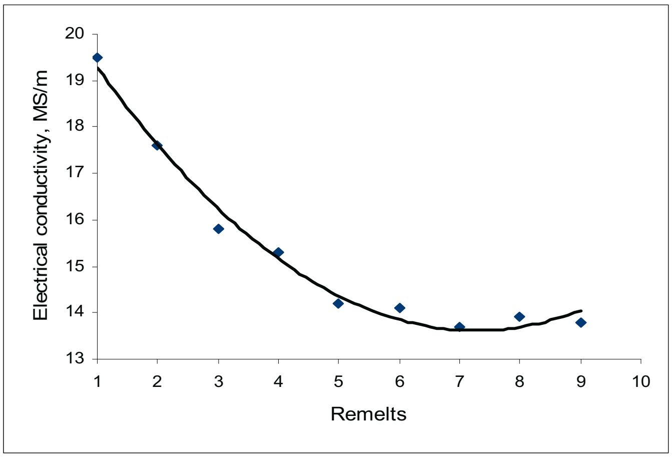

Fig. 1 Electrical conductivity of F3S.10S composite after multiple remelting

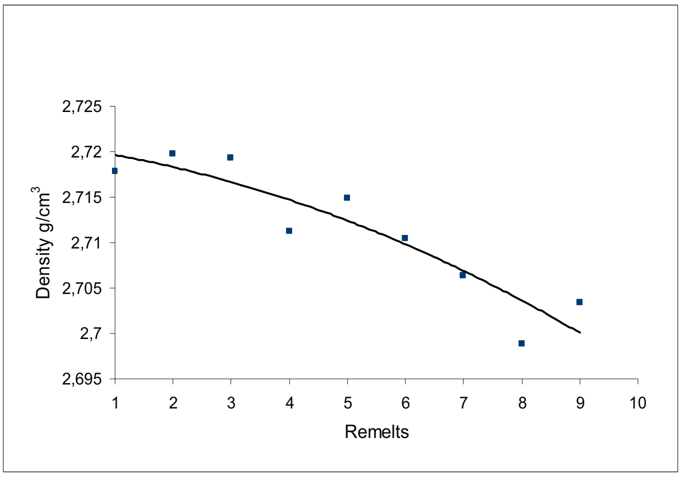

Fig. 2. Density of F3S.10S composite after multiple remelting

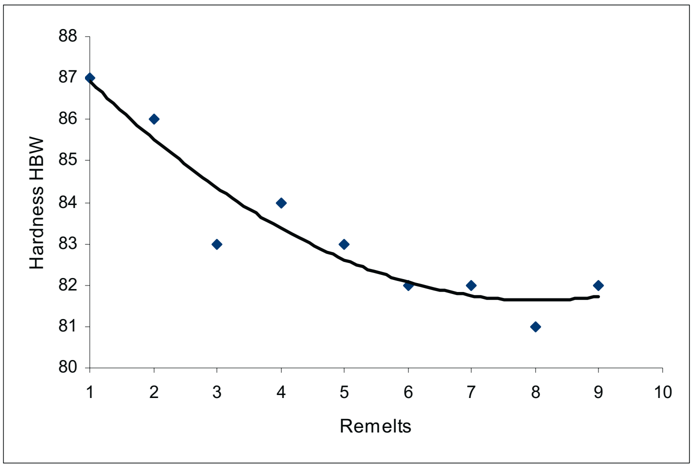

Fig. 3 Hardness (HBW) of F3S.10S composite after multiple remelting

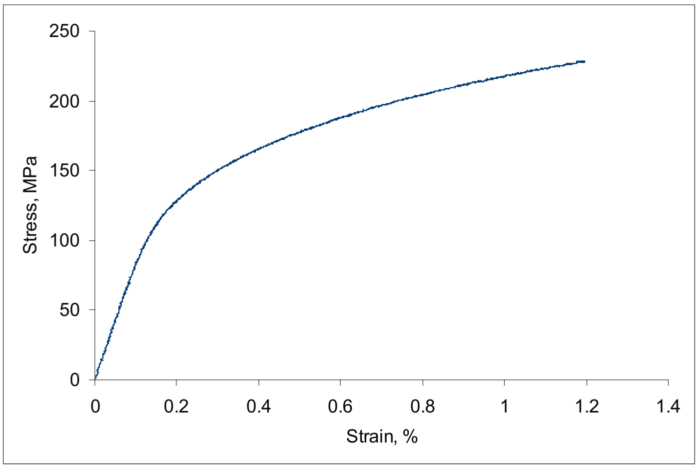

Fig. 4 The representative static tensile test curve for F3S.10S composite after first remelting

As expected, electrical conductivity is the most sensitive to such treatment that is evidenced by its continuous decrease up to 5th remelt with about 30% reduction, compared to the 1st remelt. However, from 6th remelt electrical conductivity remains almost constant. Similar property-remelt number relationship is noted for hardness, contrary to density that decreases monotonically up to the last 9th remelt.

Fig. 4 shows the representative static tensile test curve recorded for the samples after the first remelting, that is typical for metal matrix in as-cast condition. Fig. 5 summarizes the measurements of tensile strength properties of composite after its multiple remelting while corresponding changes of mechanical properties after each remelting are collected in Tab. 2 as average values calculated for five tensile test samples. These results demonstrate the tendency for continuous decrease of all mechanical properties after successive remelting. After 9th remelting, the highest reductions are noted for tensile strength (ΔR_m=-21%) and elongation (ΔA =-25%) while the smallest one for Young modulus (ΔE = -13%). Elastic limit $R_{0.05}$ and yield point $R_{0.2}$ also show the decreasing tendency (up to - 20% compare to the 1st remelting). However, the decrease of mechanical properties is not monotonic between individual remelts that can be explained by local segregation of reinforcing phase coupled with none-uniform distribution of porosity, caused from increase of the degree of poisoning with gas after successive composite recasts and evidenced by density measurements. For example, R_m after 5th remelting is as high as that after 1st remelting while the lowest values correspond to 6th and 9th remelts. What is interesting, occasionally both Young modulus (E) and elongation (A) demonstrate the higher values relatively to the 1st remelt. This fact, as evidence of much higher sensitivity of composite material than its matrix for the liquid metal treatment that results in much bigger scattering of experimental data as well as in smaller repeatability of measurements. It should be taken into consideration in development of proper recycling procedures.

Fig. 6 shows the representative microstructures of F3S.10S composite after 1st and 9th recasts. Under optical microscopy magnifications, structural characterization of F3S.10S composite after multiple remelting does not demonstrate any remarkable changes, compared to as-received composite. Moreover, there is no degradation of SiC particles while the qualitative invariability of the reinforcing phase morphology is ascertained within the range of its content and distribution independent on remelt number.

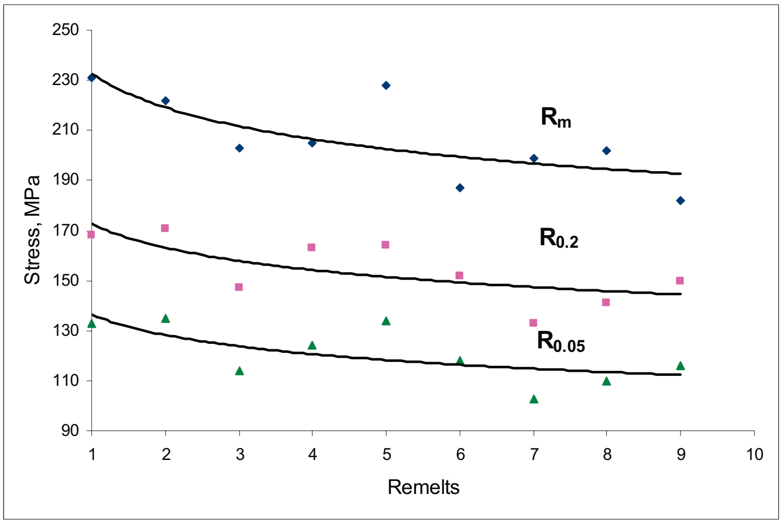

Fig. 5. Change of tensile strength properties of F3S.10S composite after successive remelts

Tab. 2. Mechanical properties of F3S.10S composite after multiple remelting

Number of remelts	Mechanical properties				
	E, GPa	$R_{0.05}$, MPa	$R_{0.2}$, MPa	R_m, MPa	A %
1	75.0	133	168	231	2.0
2	68.4	135	171	222	2.1
3	72.0	114	147	203	2.2
4	77.0	124	163	205	1.6
5	72.6	134	164	228	2.2
6	73.1	118	152	187	1.6
7	86.4	103	133	199	2.2
8	67.7	110	141	202	2.3
9	65.6	116	150	182	1.5
Percentage change between 1st and 9st remeltings	-13%	-13%	-11%	-21%	-25%

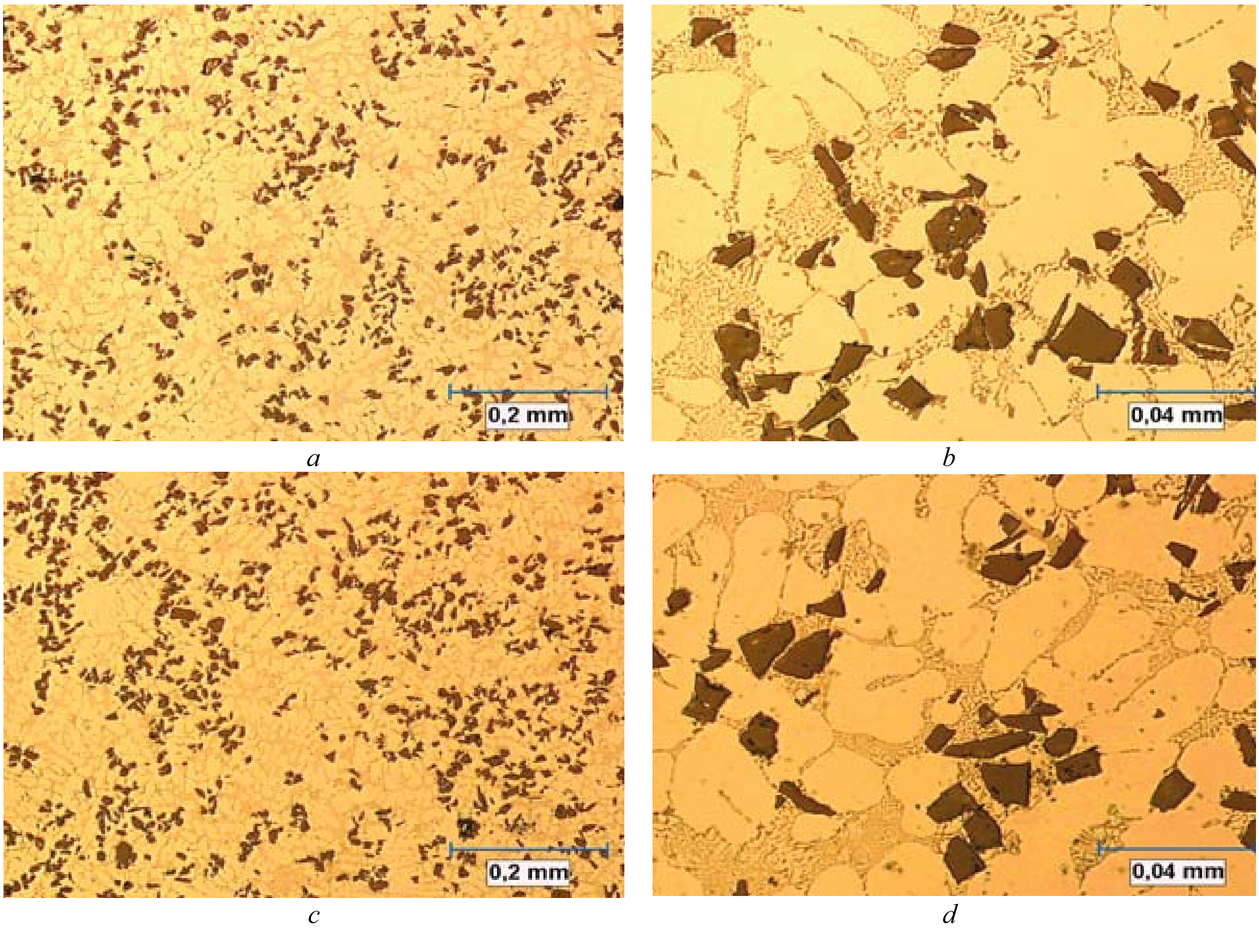

Fig. 6. Microstructure of F3S.10S composite after 1st (a, b) and 9th (c, d) remelting under different magnification: 100× (a, c) and 500× (b, d)

4. Summary

Multiple remelting (up to nine times) of F3S.10S composite followed by its gravity casting to the cast iron die does not cause any important changes in composite microstructure noticeable under optical microscopy magnifications. However, both physical as well as mechanical properties show continuous reduction with number of subsequent remelts thus demonstrating one of the possible negative effects of recycling on the composite materials properties. After 9th remelting, the highest degree of reduction was recorded for elongation (-25%) and electrical conductivity (-30%), as parameters that are the most sensitive to even insignificant changes in materials microstructure. In the same time, the decrease in the composite hardness and Young modulus is much less, i.e., only -10% and - 13%, respectively.

Nevertheless, in the face of occasional increase in a given property from one remelt to another, these preliminary investigations suggest the possibility to improve recycling process by proper selection of liquid metal treatment and subsequent casting procedure.

References

[1] Rudnik, D., Sobczak, J., *Tłoki kompozytowe do silników spalinowych,* ISBN 83-913045-7-4, Instytut Transportu Samochodowego, Warszawa 2001.

[2] Sobczak, J., *Kompozyty metalowe*, ISBN 83-913045-8-2, Instytut Odlewnictwa, Instytut Transportu Samochodowego, Kraków-Warszawa 2001.

[3] Wojciechowski, A., Sobczak, J., *Kompozytowe tarcze hamulcowe pojazdów drogowych*, ISBN 83-913045-6-6, Instytut Transportu Samochodowego, Warszawa 2001.