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Mechanical properties and deformation behavior of Al/Al7075, two-phase material

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ABSTRACT

In the present study, mechanical properties and deformation behavior of Al/Al7075, two-phase material were investigated. The two-phase materials were fabricated by mixing commercially pure Al powder with Al7075 chips and consolidating the mixture through hot extrusion process at 500 °C. Mechanical properties and deformation behavior of the fabricated samples were evaluated using tensile and compression tests. A scanning electron microscope was used to study the fracture surface of the samples including different amount of Al powder, after they were fractured in tensile test. The results of the tensile and compression tests showed that with decreasing the amount of Al powder, the strength increases and ductility decreases. Calculation of work hardening exponent (n) indicated that deformation behavior does not follow a regular trend. In a way that the n value was approved to be variable and a strong function of strain and Al powder wt% of the sample. The results of the fractography studies indicate that the type of fracture happened changes from completely ductile to nearly brittle by decreasing the wt% of Al powder from 90% to 40%.

1. Introduction

Amongst the different types of materials, aluminum and its alloys are commonly used in industry. The waste of these materials usually has the form of chips coming out of the machining of semi-finished products. The chips of aluminum are very difficult to recycle by conventional methods due to their elongated spiral shape, small size, surface contamination with oxides, machining oil, etc. In recent years, some alternative processes have been suggested to recycle aluminum chips using powder metallurgical techniques. Zapata et al. [1] presented a process by which they succeeded to convert the chips into powder through ball milling. The obtained powder was then cold pressed and hot extruded, with and without ceramic particulates, to produce aluminum alloys or aluminum matrix composites. Gronostajski et al. [2,3] also have presented a process for recycling aluminum chips and producing metallic composite materials. In this process the chips were granulated by means of a cutting device, and then the produced particles were mixed with tungsten or iron–chromium powder. After that the mixture were milled in a high-energy ball mill, cold pressed and hot extruded to produce composite materials. These alternative recycling processes have in common the material transformation from chips to powder by milling. Fogagnolo et al. [4] employed a new technique in which they recycled the material directly from the chips formed by cold or hot pressing followed by hot extrusion, avoiding the milling step, which results in a more economic recycling process. This new technique can also be employed to recycle chips obtained from aluminum matrix composites machining, which is still more difficult to obtain by other techniques.

Recent investigations showed that the hardness and the tensile properties of the recycled materials are slightly lower than metallurgically produced materials which are in turn due to the residual porosity and the imperfect bonding between the chips after the hot extrusion process [5]. To obtain better bonding, and as a result improved mechanical properties of the extruded products, the present authors used Al powders as a binder in recycling of Al7075 chips through hot extrusion process, that its results will be published elsewhere [6]. In the current study, mechanical properties and deformation mechanisms of the Al/Al7075 two-phase materials were investigated in more details.

2. Materials and processing

Rectangular cube shape Al7075 chips with an average size of 1 mm × 1 mm × 0.11 mm and air-atomized commercially pure Al powder with the average particle diameter of about 45 μm were used as the starting materials. The details of the procedure used for preparing the samples required for evaluating their mechanical properties and also their plastically deformation behavior has been recently under gone publication elsewhere [6]. In summary, to fabricate the samples, the Al 7075 chips were mixed with different amount of Al powders in the range of 20–90 wt%, using a simple mixing drum. Consolidation

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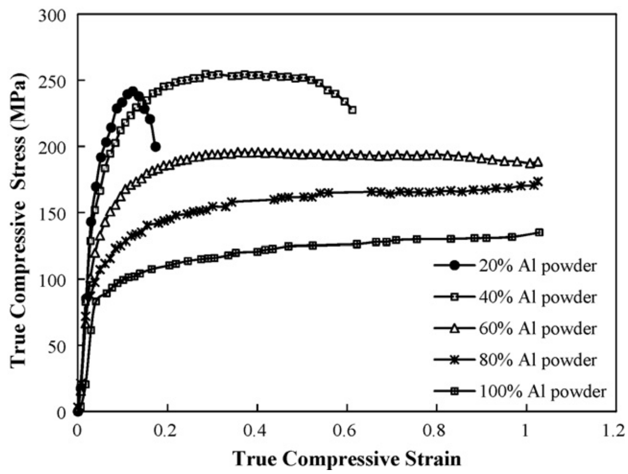

Fig. 1. Compressive true stress–strain curves for the samples including different amount of Al powder.

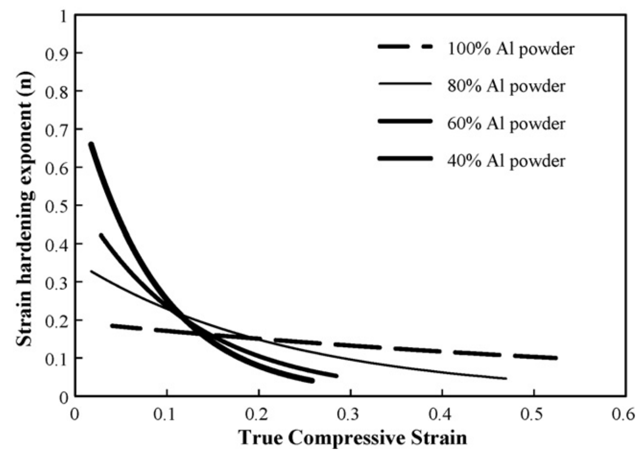

Fig. 2. n versus strain for the samples including different amount of Al powder.

was carried out by hot extrusion process at 500 °C with an extrusion ratio of about 12. Mechanical performance of the produced two-phase samples was evaluated by both compression and tensile tests at room temperature. The tensile samples were prepared according to the ASTM-E8 standard. The tensile tests were carried out with an initial strain rate of $3.5 \times 10^{-3}\,s^{-1}$ in the direction of the pressing axis. The compression test was carried out on the samples with an H/D ratio equal to 1.5 with strain rate of $6.75 \times 10^{-3}\,s^{-1}$ in the direction of the pressing axis. The fracture surface of the tensile samples was studied using a scanning electron microscope (SEM).

3. Results and discussion

3.1. Compression test

Fig. 1 shows the compressive true stress–strain curve for the samples including 20, 40, 60, 80, and 100 wt% of Al powder extruded at 500 °C. The curves reveal that with decreasing the wt% of Al powder, the strength increases and formability decreases, except for the sample including 20 wt% Al powder which shows non-acceptable strength and formability. By decreasing the wt% of Al powder, an increase in compressive strength is expected which is because of the higher strength of Al7075 alloy chips than pure Al, and also the fine grain structure of the chips. In other words, high strength Al alloy chips play the role of reinforcement in the soft Al matrix, and therefore, by increasing the percentage of the reinforcement, the strength increases. For the sample including 20 wt% Al powder which is produced by extrusion at 500 °C, the mechanical properties was not acceptable and far from what expected. In fact for this sample, the amount of Al powder (20 wt%) is not enough to properly fill the space between the chips, and cannot act as a good binder when the mixture is extruded at 500 °C.

3.2. Work hardening exponent

With respect to the results of compression tests (Fig. 1), for the samples including different amount of Al powder, all extruded at 500 °C, work hardening exponent, n, is plotted as a function of strain (Fig. 2). It is well known that for annealed materials, n is constant and is lower for higher strength materials. But for these samples the trend was different. As Fig. 2 shows, the n value is a function of strain, and it decreases with increasing the strain. But according to Fig. 3, which shows the rate of n variation versus strain, decreasing rate is not constant, in a way that n value at first decreases rapidly with increasing strain but then it reaches a steady value and its variation becomes negligible. At small strain, the samples with higher strength (including lower amount of Al powder) have higher n value. But in these samples, also, n decreases with higher rate (Fig. 3), and so the curves obtained for the samples including different amount of Al powder cross each other at a specified strain. After the crossing point, the trend reverses and follows a regular and known trend (i.e., n is lower for higher strength materials), but it also is a function of strain. It can be seen in Fig. 3 that the rate of variation becomes equal for all the samples and it approaches to zero. The high initial work hardening is similar to the effects observed in some aluminum metal–matrix composites [7] and Al–Mg alloy with bimodal microstructure [8]. This behavior can be attributed to the two-phase structure of the materials produced in this work. In fact, the produced materials consist of two different phases that one of which is significantly softer. At small strain, deformation is localized in Al powders. For the samples including lower wt% of Al powder, strain localization is more severe, in a way that small portion of material stands large strain, and so the material shows unusual high n value. By increasing the strain, the small Al powder region is work hardened by relatively a small increase in strain and its strength increases, and so the chips region is also started to be deformed. In the samples with higher amount of chips, because of more severe strain localization in Al powder regions, the strength of this regions increases more rapidly which results in a higher rate decrease of the n value. As a result of chips region deformation, the n value decreases and shows usual trend. The n value becomes a constant value (n

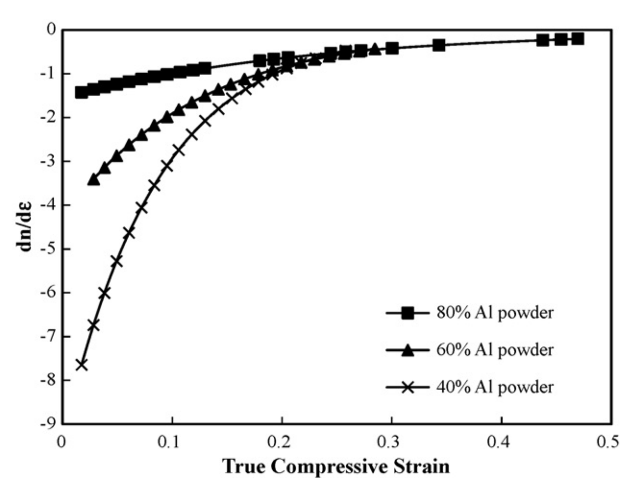

Fig. 3. Variation rate of n versus strain for the samples including different amount of Al powder.

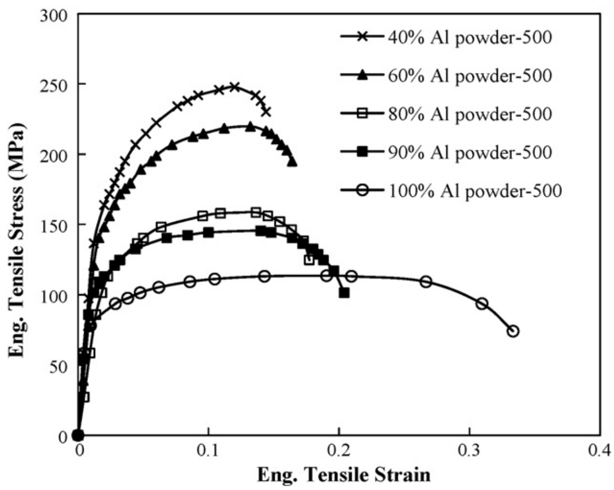

Fig. 4. Tensile engineering stress–strain curves for the samples including different amount of Al powder.

variation approaches zero) for all the samples as the deformation becomes uniform in the material. The results showed that n value was approximately constant for the sample including 100% Al powder, confirming that the variation of the n value with strain is due to the two-phase structure of the new material produced in this research work.

3.3. Tensile test

Fig. 4 shows the tensile engineering stress–strain curves for the samples including 40, 60, 80, 90 and 100 wt% of Al powder produced by extrusion at 500 °C. And Fig. 5 shows the yield strength at an engineering strain of 0.2 pct (S_y), ultimate tensile strength (UTS), uniform strain (e_u%), and elongation to failure (e_f%) for these samples as a function of wt% of Al powder. It is observable that with decreasing the wt% of Al powder, the yield strength and ultimate strength increase, and the ductility and uniform strain decrease. The yield and ultimate strength have been equally affected by the variation of Al powder wt%, so the ratio of S_u/S_y is approximately constant for the samples with different amount of Al powder and is approximately equal to 1.57. The ratio of monotonic UTS to the 0.2 pct offset yield strength shows that all the samples behaved as ductile materials and undergo cyclic hardening under cyclic stress [9]. But the amount of chips does not have a similar effect on uniform strain and elongation to failure. So that with decreasing the wt% of Al powder, e_f decreases with higher rate, and therefore the difference between e_u and e_f decreases. And so the major difference in the ductility of the samples is as a result of post-uniform elongation.

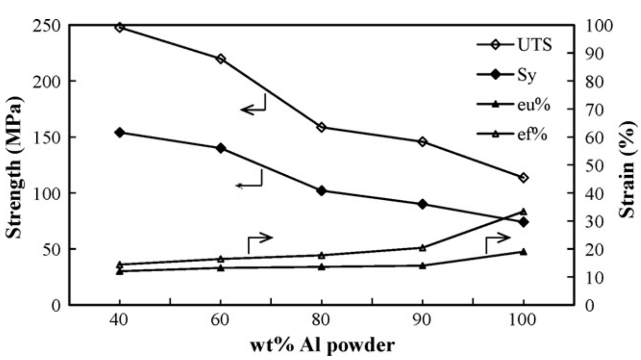

Fig. 5. Variation of the yield strength at an engineering strain of 0.2 pct, ultimate tensile strength (UTS), uniform strain (e_u%) and elongation to failure (e_f%) versus Al powder wt%.

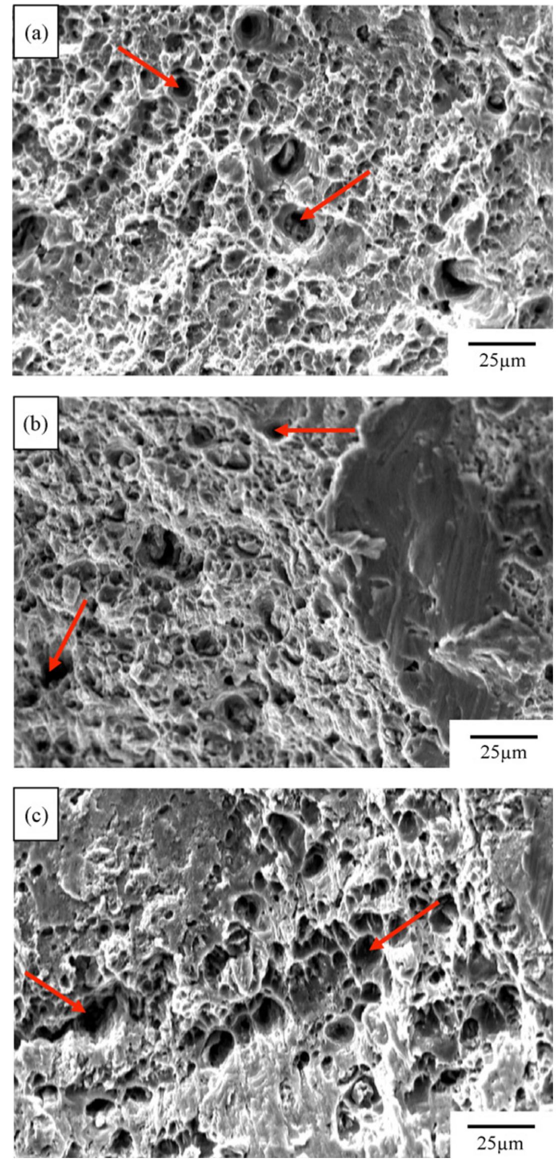

Fig. 6. SEM microgragh s of the fracture surface for the samples including (a) 90 wt% Al powder, (b) 60 wt% Al powder and (c) 40 wt% Al powder, in all three figures some of the voids created during ductile fracture are shown by arrows.

3.4. Fractography

Fig. 6 shows the fracture surface of the tensile samples. The fracture surface of the sample including 90 wt% Al powder (Fig. 6a) indicates that the fracture of this sample is completely ductile. Also, small continuous voids and well-defined dimples can be observed. The existence of small voids (some of them are indicated by arrow on the presented micrographs) confirms that the fracture of this sample is arisen by nucleation and growth of voids. The fracture surface of the samples including 60 and 40 wt% Al powder (Fig. 6b and c, respectively) shows a mixture of ductile and brittle fracture. In fact, the fracture surfaces of these samples include both small and large connected voids. Also in a few parts, smooth surfaces are created, due to the brittle fracture of relatively hard chips. Regarding the microgragh s presented in Fig. 6, it can be seen that the contribution of brittle fracture, in the fractures happened, increases by decreasing wt% of the Al powder in samples.

4. Conclusions

In summary, the main points of the present study are summarized in the following statements;

1. With increasing Al powder content, both tensile and compressive strength decrease and ductility and formability increase.
2. At high amount of chips wt%, Al powder cannot act as a good binder, therefore the samples, extruded at 500 °C do not show acceptable mechanical properties.
3. For the Al/Al7075 two-phase material, investigated in the present study, work hardening exponent is a function of strain and amount of Al powder wt%, and decreases with increasing the strain. At the initial strain, the samples with lower amount of Al powder have higher *n* value. But *n* itself also decreases more rapidly for these samples. At higher strain, the samples with higher amount of Al powder have higher *n* value and the trend becomes regular. Also the variation of *n* approaches to zero for all the samples.
4. In the tensile test, the yield and the ultimate tensile strength (UTS) increase with decreasing the Al powder wt%, approximately with equal rate. But with decreasing Al powder wt%, uniform strain (e_u%) decreases with a lower rate than elongation to failure (e_f%).
5. The investigation of fracture surface shows that with decreasing Al powder wt%, the portion of brittle fracture increases.

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