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A novel method for the production of metal powders without conventional atomization process

A. Canakci*, T. Varol

Department of Metallurgical and Materials Engineering, Engineering Faculty, Karadeniz Technical University, Trabzon, Turkey

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ABSTRACT

Fabrication of Al alloy powders from recycling chips by mechanical milling is a novel processing technique. In this study, the mechanical milling was applied to the production of AA7075 powders from the recycling chips. The effect of milling time on the morphology, particle size and powder yield of the milled chips and fabricated powders was investigated. Fabricated powders were characterized by a scanning electron microscope (SEM), a Laser Particle Size Analyzer, X-ray diffraction (XRD) and energy dispersive spectroscopy (EDS). A chip milling model based on the morphology and size of milled powders were presented. It was found that after 10 h of milling, the average particle size of the AA7075 powders was reduced to 35 μm. Results showed that 5 h of milling was the critical milling time in a change in the chip morphology (segmented shape) from powder morphology (irregular shape). The particle size of fabricated powders after 10 h of milling was about 286 times lower than that of initial chips.

1. Introduction

Metal processing and similar industries related to manufacturing processes such as machining, surface finishing and painting have been accepted as polluting industries. The most discussed issues associated with metal processing/products, machinery and automotive sectors are consumption of large amounts of raw materials and energy (Alkaya and Demirer, 2013). The waste of raw materials and energy consumption can be prevented using effective recycling methods (Hatayama et al., 2012; Koyanaka and Kobayashi, 2010).

Al and its alloys have significant technological importance in automotive, defense and aircraft industries due to their light weight and high specific strength. Machining is one of the most important processes used for manufacturing semi-finished and final products of Al and Al alloys by removing the excess parts in the form of small chips. The amount of chips fabricated as a result of machining process is sufficiently large so that recycling of the machining chips is required for industrial and environmental reasons. Casting is generally supposed as a traditional method for recycling the Al and Al alloy chips. However, in the past two decades, recycling the chips by casting has been revealed to be an energy consuming, environmental destroying, and high cost process. Moreover, it was found that 46–48% of the Al chip mass became a loss during recycling using the casting process (Gronostajski et al., 2000; Samuel, 2003; Mahboubi Soufiani et al., 2010; El Aal et al., 2013). The different production methods namely centrifugal atomization (Plookphol et al., 2011), water atomization (Liu et al., 2011), chemical vapor deposition (CVD) (Jovic et al., 2006), electrolysis (Orhan and Hapçı, 2010) and mechanical milling (Varol and Canakci, 2013; Canakci et al., 2013a,b; Canakci et al., 2012) have been used to produce metal and composite powders which have superior mechanical (hardness) and physical properties (apparent density, size and shape). These metal powder production processes differ in their production rate, structure and morphology of the obtained materials and the economical aspects especially in energy consumption. However, the main goals which become prominent in high-tech applications are controlled and adjustment of particle size, structure and morphology (Liu, 2000; Kandjani et al., 2010). The atomized powders usually have a broad size distribution, which can affect not only production cost but also compact density. The amount of powder fabricated by atomization methods is very low and the use of expensive inert gas (argon or helium) is needed to prevent oxidation (Liu et al., 2011). Moreover, the conventional casting process sequence consists of four major steps: (1) Consolidation of metal chips, (2) Melting of chip billets by using a furnace, (3) Atomization of melting metals, (4) The process of sieve analysis. However, the production of metal powders from the chips can be

* Corresponding author. Tel.: +90 462 3772927.
E-mail address: aykut@ktu.edu.tr (A. Canakci).

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provided by mechanical milling in a single step. Even though the ultrafine metal powders with high purity can be obtained in chemical vapor deposition, they tend to have a broad size distribution because the nucleation and the particle growth proceed simultaneously. Also, this technique is not suitable for the mass production of the metal powders due to the difficulty of the technique and the expensive cost (Kim et al., 2004). The powders fabricated by electrolysis method have high purity but this method is very expensive. (Mojtahedi et al., 2011). Mechanical milling (MM) applies high energy impacts on the charged chip and powder by ball-powder-ball and ball-powder-vial collisions causing severe plastic deformation, repeated fracturing and cold welding of the particles leading to micron and sub-micron powders (Alam, 2006; Suryanarayana, 2001, 1995; Gleiter, 2000). Mechanical milling of powder particles has created a significant alternative to other production methods in preparing nanocrystalline powders, nano powders, composite powders and intermetallics with a broad range of composition and structures in recent years. Mechanical milling is a powder processing technique and it is especially useful for the fabrication of composite and alloy powders that are difficult to prepare by conventional processes due to high vapor-pressure or large differences in the melting temperature of the components (Alam, 2006; Murty and Ranganathan, 1998; Malow and Koch, 1998). The mechanical milling offers powders having superior properties such as a narrow broad size distribution as compared with other powder production methods such as atomization, chemical vapor deposition and electrolysis. Moreover, the mechanical milling has shown great potential in synthesizing a wide variety of nanocrystalline powders, metal matrix composite powders and alloy powders with unique properties. Gogebakan et al. (2013) synthesized nanocrystalline CuMgNi alloy powders mechanical milling from mixtures of pure crystalline Cu, Mg and Ni powders using a planetary ball mill with different ball to powder ratio. They observed that the average particle size of the as-received powders decreased with increasing milling time due to refinement of particle size and accumulation of internal strain in the early stage of milling process. Moreover, in recent years, a number of studies have also been reported on alloys and metal matrix composites produced by consolidation of machining chips using mechanical milling and powder metallurgy method. For instance, Sherafat et al. (2009) investigated the possibility of recycling Al7075 alloy chips with the help of commercially pure Al powders, via powder metallurgy method and hot extrusion process. They studied the effect of Al powders and their amounts on the mechanical properties of the recycled chips. According to their results the strength increased and ductility decreased with increasing the amount of chip in the samples. Gronostajski et al. (1998) presented an alternative process, where chips of Al and its alloys are cut or milled converted directly from hot plastic working into final products. They observed the hardness and mechanical properties of Al and $AlMg_2$ base composites are slightly lower than those of monolithic materials. The alternative process does not have any harmful effects on the environment and the material produced can be further processed by other plastic working methods such as forging and rolling.

Although the nanocrystalline powder, the composite powder fabricated by mechanical milling of as-received powders and metal matrix composite produced from the machining chips via powder metallurgy method have been reported, powder production from the machining chips by mechanical milling, stages of milling, structural evolution and characterization of synthesized powders has not been studied. Therefore, the purpose of the present work was to: (a) produce AA7075 powders from the machining chips by mechanical milling; (b) investigate the stage of milling of chips; (c) examine the change of morphology and size of chips with increasing milling time. This study is important because it introduces a novel method to produce the alloy powders, pure metal powders, nanocrystalline powders, nano powders, composite powders and nanocomposite powders from the recycling machining chips.

2. Experimental procedure

AA7075 chips with the composition of 1.08% Cu, 0.15% Si, 2.72% Mg, 0.03% Mn, 0.05% Ti, 0.11% Cr, 0.22% Fe, 5.5% Zn and 90.14% Al (in wt.%) were fabricated during machining of a rod billet in a lathe (Fig. 1a). EDX spot analysis performed from three different points on the billet material was given in Table 1. Segmented type chips were obtained during turning operation. After turning operation, AA7075 chips were cut into chips by double roller crusher (Fig. 1b). The final dimensions of the chips were 10 mm × 2 mm × 0.5 mm, after the cutting process (Fig. 2), after the crusher process (Fig. 1c). The chips were milled using high energy planetary Fritsch ball mill (Pulverisette 7, Premium line) for 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 h in WC vials. To prevent excessive cold welding of the particles, methanol (2 wt. %) was used as a process control agent (PCA). The milling speed of 400 rpm and ball-to-powder weight ratio of 30:1 were used. 5 g chip was milled in every milling process. Samples

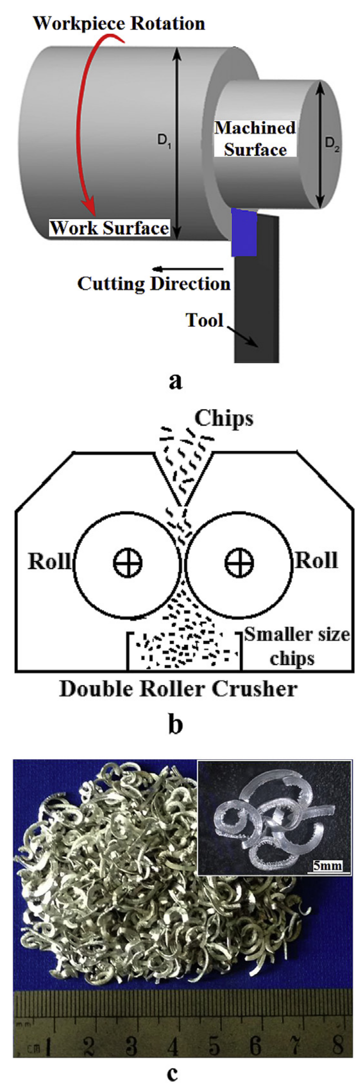

Fig. 1. Production stage of initial chips; (a) Turning operation, (b) roller Crusher, (c) broken chips with the roller.

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