ENHANCED MECHANICAL PROPERTIES OF METAL MATRIX COMPOSITES WITH NANOCERAMICS/ NANOCLAY ON MACHINABILITY

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Abstract

Transmission electron microscopy (TEM) was used to study the particle size of the nanopowder. The metal matrix composites (MMCs) were manufactured by liquid metallurgy technique using vortex method. Aluminium-6061 (Al-6061) alloy was used as matrix which is reinforced with 2, 4 and 6 weight percentage of α-Al2O3 nanoceramic powder. Scanning electron microscopy (SEM) analysis was used to study the distribution and homogeneity of the α-Al2O3 particles in the Al-6061 matrix. Results show that addition of α-Al2O3 nanoceramic powder as reinforcement has a drastic effect on the mechanical properties like hardness, compression strength and ultimate tensile strength (UTS) of the MMCs when compared with that of Al-6061 matrix. Further, the increased % age of α- Al2O 3 nanoceramic powder contributed in increased hardness, compression strength and ultimate tensile strength the MMCs. In the current article solution combustion synthesis method was used to prepare α-Al2O3 nanoceramics. Powder x-ray diffraction (PXRD) studies were done to study the phase formation and calculate crystallite size of α-Al2O3 nanoceramics. In this study, machinability test was conducted on Al-Nanoclay metal matrix composites using lathe tool dynamometer. Composites were prepared with aluminium as the matrix and nanoclay particles with 2, 4, 6 percentage by weight as reinforcement. The effect of clay particles and machining parameters such as cutting speed, feed rate and depth of cut on tangential force and chip formation was studied. From the results it is observed that the tangential force applied by the tool on MMC, facilitate chip breaking and the generation of chips significantly depends on feed but almost independent of speed. These results reveal the roles of the nanoclay reinforcement particles on the machinability of MMCs and provide a useful guide for a better control of their machining processes.

Key words: Cutting Speed, Chip breaking, Depth of Cut, Feed rate, Machinability.

1. Introduction

In the current days aluminum alloys are preferred engineering material for automobile, aerospace and mineral processing industries for various high performing components that are being used for varieties of applications due to their excellent thermal conductivity properties. Among several series of aluminum alloys heat treatable Al-6061 and Al-7075 are much explored, among them Al-6061 alloy are highly corrosion resistant and are of excellent extricable in nature and exhibits moderate strength and finds much more applications in the fields of construction, automotive and marine applications. The MMCs formed out of aluminum alloys are of wide concern due to their high strength, fracture hardiness, wear resistance and stiffness. Further these MMCs are of superior in nature for elevated temperature application when reinforced with ceramic particle [1]. The use of Al-6061 MMCs has been limited in very specific applications such as aerospace and military weapon due to high processing cost. In the recent days, Al matrix composites have been used for the production of automotive parts such as engine piston, cylinder liner, brake disc/drum etc. [2]. Manufacturing techniques for Al-MMCs can be classified into three types such as (a) liquid state processing, (b) semisolid processing and (c) powder metallurgy [3, 4]. Particulate reinforced Al-MMCs can be processed more simply by the liquid state i.e. melt-stirring method. Melt stir casting is an attractive processing method since it is comparatively cheaper and offers a broad selection of materials and processing conditions. Amongst the material variables, the mechanical properties of fiber and matrix, particularly the failure strains, interface properties and fiber configuration play important role in determining fracture resistance and damage tolerance of the composites[1-2]. Nanostructure materials such as nanocomposites provide opportunities to explore new fracture behavior and functionality beyond those found in conventional materials. The presence of small amounts of nanoparticles in metal matrix can improve the wear resistance and hardness of composites. Obviously, the higher the hardness of the material, the more the abrasive wear experienced by the cutting tool in addition. Nevertheless the incorporation of the microsize hard particles makes the machining of MMCs difficult [3], and diamond tools are often necessary [4]. There have been some investigations on the machining of MMCs, dealing with tool wear [5], surface / subsurface quality [6] and chip formation [7]. However until now, no particular work is done exclusively to assess the importance of nanoclay content on the machinability parameters.

2. EXPERIMENTAL DETAILS

The matrix material used for the MMCs in this study, Al, has excellent casting properties and reasonable strength. This alloy is best suited for mass production of lightweight metal castings. chemical composition of Al6061 shown below

1. Silicon minimum 0.4%, maximum 0.8% by weight
2. Iron no minimum, maximum 0.7%
3. Copper minimum 0.15%, maximum 0.40%
4. Manganese no minimum, maximum 0.15%
5. Magnesium minimum 0.8%, maximum 1.2%
6. Chromium minimum 0.04%, maximum 0.35%
7. Zinc no minimum, maximum 0.25%
8. Titanium no minimum, maximum 0.15%
9. Other elements no more than 0.05% each, 0.15% total
10. Remainder Aluminum

The nanoclay of 10-60 nm size were used as the reinforcement and the nanoclay content in the composites was varied from 2 to 6% in steps of 2% by weight. Liquid metallurgy technique was used to fabricate the composite materials in which the clay particles were introduced into the molten metal pool through a vortex created in the melt by the use of an alumina-coated stainless steel stirrer. The coating of alumina on the stirrer is essential to prevent the migration of ferrous ions from the stirrer material into the molten metal. All the chemicals and reagents used in this study were of analytical grade. Commercially pure aluminium nitrate (Al(NO3)3 9.H2O, 99% Merck), urea (CO(NH2)2 99% Merck) were used. Al-6061 alloy which is available commercially and exhibits excellent casting properties and reasonable strength, was used as base alloy. This alloy is best suited for mass production of lightweight metal casting. The chemical composition of Al- 6061matrix is given in table 1.

Table 1: The chemical composition of Al- 6061

Mg	Si	Fe	CU	Ti	Pb	Zn	Mn	Sn	Ni	Al
0.8-1.5	10-12	1	0.7-1.5	0.2	0.1	0.5	0.5	0.1	1.5	Bal

Synthesis of α-Al2O3 nanoceramics:

α-Al2O3 nanoceramic powder was prepared by solution combustion method [19-22]. Aluminium nitrate and urea was used as oxidizer and fuel respectively, precursor mixture was stirred well for about 20 min with distilled water, then it was introduced into the preheated muffle furnace at 500 °C (±10 °C). Entire mixture catches fire, burned and transformed into a white crystalline powder in very short period of 5 min. The overall reaction can be written as,

$$2Al(NO_3)_3 + 3CO(NH_2)_2 \rightarrow Al_2O_3 + 6H_2O + 6N_2 + 3CO_2 \quad (1)$$

Characterizations of α-Al2O3 nanoceramics and MMCs

Powder X- ray diffraction patterns was recorded on a Shimadzu XRD-700 X-ray Diffractometer with CuKα radiation with diffraction angle range $2\theta = 20^{\circ}$ to 80° operating at 40 kV and 30 mA. HR-TEM analysis was performed on a Hitachi H-8100 (accelerating voltage up to 200 KV, LaB6 Filament). SEM performed on a ZEISS ULTRA 55 scanning electron microscope.

MMCs preparation

The liquid metallurgy route using vortex technique is employed to prepare the MMCs. A mechanical stirrer was used to create the vortex. The reinforcement material used was α-Al2O3 nanoceramic powder. The weight percentage of nanoceramic powder used was 2, 4 and 6 weight percentages in steps of 2%. Addition of nanoceramic into the molten Al-6061 matrix melt was carried out by creating a vortex in the melt using a mechanical stainless steel stirrer coated with alumina (to prevent migration of ferrous ions from the stirrer material to the Al alloy). The stirrer was rotated at a speed of 450 rpm in order to create the necessary vortex. The α-Al2O3 nanoceramic powder was pre heated to 450 ºC and added in to the vortex of liquid melt at a rate of 120 g/min. The MMCs melt was thoroughly stirred and subsequently degasified by the addition of degassifier. Castings were produced in permanent moulds in the form of cylindrical rods. (Diameter 30 mm and length 150 mm). The castings of MMCs were subjected to machining in CNC lathe to get the specimens for mechanical properties. The matrix alloy was also casted under identical conditions and machined for comparison.

3. Results and discussion

The formation of nanocrystalline phase of the combustion derived α-Al2O3 was confirmed by PXRD measurements. The PXRD of α-Al2O3 powder show the crystalline nature having rhombohedral structure (matched with ICDD card number 46-1212 with space group R-3c (No-167)), and cell parameters a = 4.7587 Å, b = 4.7587 Å, c = 12.9929 Å. All the diffraction peaks can be indexed to (0 1 2), (1 0 4), (1 1 0), (0 0 6) (1 1 3), (2 0 2), (0 2 4), (1 1 6), (2 1 1), (1 2 2), (0 1 8), (2 1 4), (3 0 0), (1 2 5) and (2 0 8) reflections. The broadening of the reflections clearly indicates the inherent nature of nanocrystals. Figure 1 shows the powder X-ray diffraction patterns of α-Al2O3 nanoceramics.

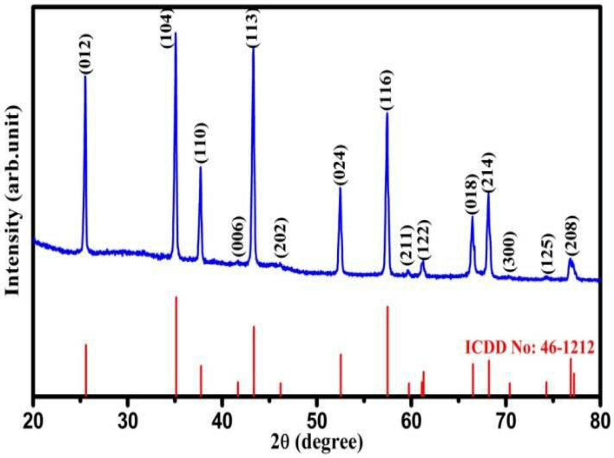

Figure 1: PXRD patterns of α-Al_2O_3 nanoceramics

Morphological analysis

Figure 2(a-b) shows SEM micrographs of α-Al2O3 nanoceramic powder. It revealed that the morphology of the nanoceramic was a nonspherical shape i.e. flakes like and has uniform size and distribution.

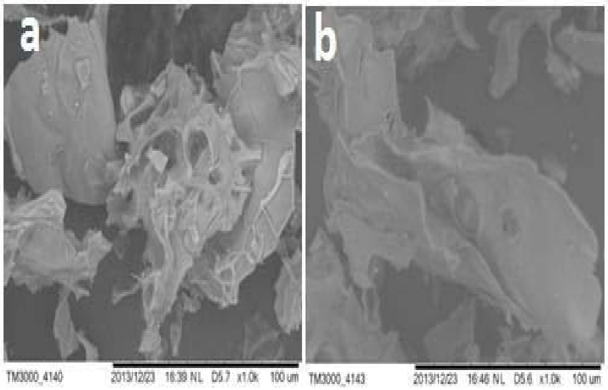

Figure 2: (a-b): SEM micrographs of α-Al_2O_3 nanoceramics

Mechanical properties

Tensile tests were conducted at room temperature using 1175 model Instron universal testing machine at a cross load speed of 0.5 mm per minute. Hardness tests were conducted in accordance with ASTM E-10 using a Brinell Hardness Tester with a ball indenter of 5 mm diameter and 500 kg load. Compression property was measured using an 1175 V model of Instron UTM at a crushed speed of 0.2 mm/minute.

Hardness

The variation of Brinell hardness values of MMCs of Al-6061 is plotted in Fig. 3b. Six specimens for each MMCs and matrix have been tested and average was calculated. The specimen used for hardness test is shown in the figure 3(a). For each MMCs material hardness increases with increase in weight percentage of α-Al2O3 nanoceramic powder in the Al-6061 matrix. The increase in hardness is probably attributed to the fact that the hard nanoceramic powder act as barriers to the movement of the dislocations within the matrix. Resistance to the indentation carried out by means of Brinell hardness test against an increase of α-Al2O3 nanoceramic content shows a substantial improvement for a larger percentage of reinforcement addition.

Compression strength

Figure 3c shows the variation of the compression tests with respect increase in the percentage of α-Al2O3 nanoceramics content in the aluminium matrix. Specimen used for compression strength test is shown in the figure 3(a). A close study of the plot indicates that the compression strength increases with the addition of α-Al2O3 nanoceramics in the matrix. Compression strength increases from 140 to 174 mPa when the weight percentage of reinforcement increases from 0 to 6. The increase in compression strength of MMCs can be attributed to decrease in inter particle spacing between α-Al2O3 nanoceramics**,** since nanoceramics is much harder than the matrix. The hard ceramic particles resist deformation stress whilst increasing composite strength of the composite.

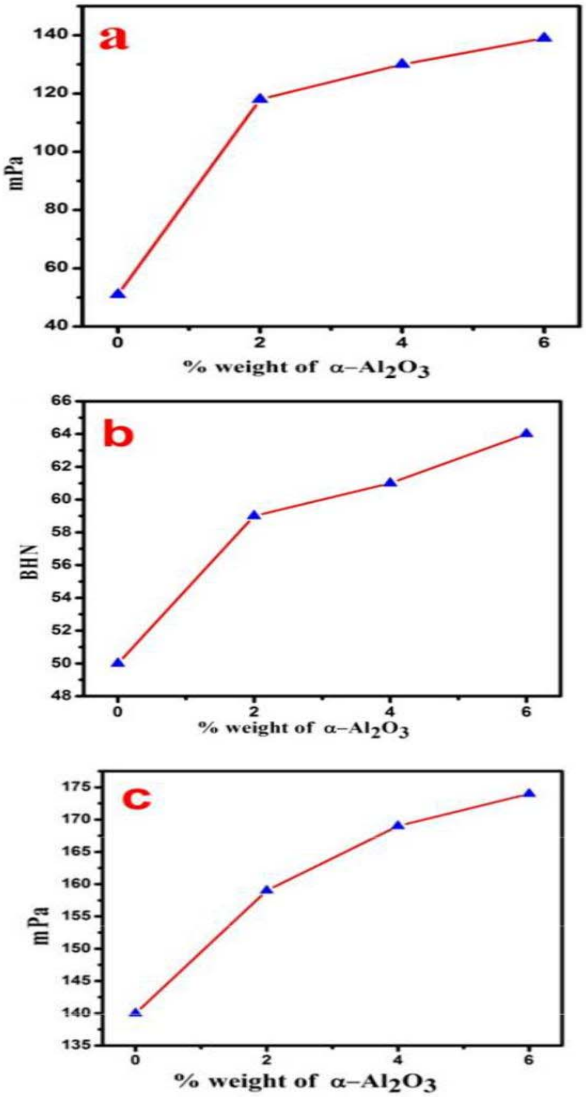

Figure 3: (a) Plot of ultimate tensile strength, (b) Plot of hardness, (c) Plot of compression strength

4. Conclusion

The important conclusion of the studies on mechanical properties of Al-6061α-Al2O3 nanoceramics reinforced Al-6061 MMCs is as follows. Solution combustion synthesis method was used to prepare α-Al2O3 nanoceramic powder. All the PXRD peaks are well matched with ICDD card number 46-1212. The results of PXRD also show that nanoceramic powder is in well crystalline nature. Liquid metallurgy route using vortex technique is employed to prepare Al-6061 MMCs material. The morphological studies revealed the uniform distribution of the ceramic particles in the matrix. Hardness of the MMCs found increased with increase in weight percentage of α-Al2O3 nanoceramics. The ultimate tensile strength of the MMCs are found higher than that of base matrix and the compression strength also increases with increase in α-Al2O3 nanoceramics. From the studies in overall it can be concluded that Al-6061 MMCs exhibits superior mechanical properties.

- ✓ The power consumed for machining the composite is higher than that of the unreinforced alloy.
- ✓ The work required for machining under similar cutting condition increases for the composite when compared to the unreinforced matrix.
- ✓ Frictional force is seen to increase in the case of the composite and to reduce it cutting conditions need to be optimized.
- ✓ Shear strain is minimum under the optimized cutting condition for the composites.
- ✓ Material removal rate increases with the depth of cut and speed for the composites when compared to the unreinforced alloy matrix.
- ✓ Power consumption and tool wear are higher for composites than that for the matrix alloy.

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