Recent Advances in Manufacturing and Machining of Aluminum based Metal Matrix Composite – A Review

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Abstract
Aluminum Metal Matrix composite is a widely used material in various automobile and aerospace applications. This material is complex to manufacture and machine due to its mechanical properties. The widely used manufacturing techniques like squeeze casing, centrifugal casting show promising results, while different machining process which are conventional and non-conventional methods are discussed. Between the different techniques discussed, squeeze casting is suitable for complex shapes. In the case of machining the laser, machining has a high removal rate, the abrasive jet has a better surface finish and tool with Chemical vapour decomposition diamond coated has a better removal rate of material compared to that of the normal tool.

1. Introduction

A Composite which is having a matrix system comprising ductile metal, which holds the reinforcement together, is called Metal Matrix Composite. These metals have high strength and wear resistance while in comparison to conventional metals. These composites require specific manufacturing techniques which are different from the conventional ones. Even while manufacturing with specific techniques, a proper mix of matrix and reinforcement should be considered calculative. Due to high strength and wear resistance capability, the machining process is also complicated in the case of metal matrix composites, and these processes have a wide range of approaches which are different from the conventional machining process.

Aluminium metal is one of the most popular metal matrix systems. This is because of their nature of lightweight and low melting temperature. The most commonly used reinforcements are silicon carbide and aluminium oxide. This is because silicon carbide increases the strength and wear resistive feature while aluminium oxide increases compressive strength. With having high wear resistive capabilities, the Al-Si or Al-Al_2O_3 composites are hard to machine using conventional techniques, as the tool will wear quickly or a high amount of force is required than usual. The commonly used manufacturing techniques and different machining processes are discussed in the following paper.

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1.1 Literature Review

Luo Zhuoxuan et al [1] Fabricated aluminium and zinc alloy matrices reinforced, with ceramic particles and graphite flakes fabricated by centrifugal casting and squeeze casting. These are tested for convectional mechanical as tribological properties. The casting output showed that the metallography as reinforcement and matrix as uniformly distributed throughout out the matrices. The mechanical properties were slightly reduced at room temperature, but the wear was uniform, and the wear rate decreased significantly.

A. Gatto et al [2] here, the tool wear of conventional tool to the tool coated with different diamond coatings are examined where conventional tool suffers from premature failure at high rake angles whereas diamond abrasive coated tools showed higher resistance, greater tool life and different chip formations.

Biing Hwa Yan et al [3] machining of the composite using rotary electro discharge were examined. The normal edm process was taking high voltages to the machine because of the wear resistance and electric resistivity of the composite. However, by the rotary discharge method combined with optimal flushing techniques, the machining gave good results.

N.P. Hung et al [4] Here, the metal matrix composite with aluminium matrix and silicon reinforcement were subjected to a machine with the conventional tool but applied fluid flow at the same time. The flow neither improved nor degraded the machining. But helped to reduce the contact temperature of the tool and remove the segregated workpieces of machining.

Hsi-Yung Feng et al [5] Here machining process was examined where the tools were coated with different types of the diamond coating. These are polycrystalline diamond coating and chemical vapour deposition coating. While machining, the initial wear was due to hard reinforcement in the mmc, but after that it was found that wear was due to abrasive and adhesive forces. The tool coated with chemical vapour deposition coating showed faster removal rates.

J. Monaghan et al [6] In this work, the non-conventional machining process are compared upon the metal matrix composites. These machining process considered are Laser Beam Machining, Electric discharge machining and abrasive jet machining. The machining was done upon aluminium silica metal matrix composite, the final comparison gave that laser machining has a high removal rate and a better surface finish was obtained with abrasive jet machining at a low feed rate.

K.C. Chan et al [7] in this work, the bending of composite matrix sheet with the help of laser beem was examined. Here aluminum metal matrix was used, which was subjected to a laser beam at a certain rate such that the sheet starts to bend because of the thermal stresses caused in the sheet due to laser. The laser feed rate limited to a certain limit as beyond that limit, the sheet starts to melt.

P.Y. Li et al [8] in this work aluminum metal matrix composite was fabricated using powder metallurgy and having damping characteristics. This damping characteristic helped to reduce the vibration in the composites in heavy machinery usage. The fabrication was done by packing aluminium and zinc together and further sintering at high temperatures. The final combination of zinc aluminium showed optimum characteristics and potential to replace aluminium alloys used in an aerospace application.

2. Manufacturing Techniques

These Metal matrix composites have a complex manufacturing process as there involves the use of more than one type of metal in the process. The improper manufacturing of the material may lead to reduced mechanical properties of the material. Different manufacturing techniques used are

1. Stir casting
2. Compo casting
3. Spray forming
4. Squeeze casting
5. Centrifugal casting
6. Powder metallurgy
7. Diffusion bonding

Among the mentioned above, manufacturing techniques Squeeze casting, Centrifugal casting and Powder metallurgy are the most commonly used techniques.

(A). Squeeze casting

This is a process where the molten material solidifies into the mould under the application of pressure. Here in the case of the composites, the reinforcement material is arranged in the mould and a hot metal matrix poured into the mould and after that, a die is used to apply pressure on the arrangement. While the pressure is applied, the metal takes the shape of the mould and the final material is removed from the mould after solidification.

(B). Centrifugal casting

This process involves the use of pressure created by the circular rotation of the mould. In this process, the die is preheated initially and rotated in a circular motion. While the die is in motion, the molten metal is poured into the die. The circular motion creates centrifugal pressure higher than the gravitational force. Thus under controlled circular motion and temperature conditions, desired materials with high finish are produced.

Centrifugal casting is an effective method of producing aluminium alloy based composites. Particle separation occurs during centrifugal casting are casted away to the outer layers based on the particle volume. The tensile strength of the ceramic reinforced mmc produced is less when compared to that of aluminium alloys, but the hardness remains significantly high in comparison to the unreinforced materials also. The particle reinforced mmc manufactured through centrifugal casting have a uniform wear rate and excellent wear resistance under lubricated conditions.

(C). Powder metallurgy

This process involves the powder preparation of different required materials and these powders are mixed together and atomized to fine particles. These particles are then compacted in the mould so that they strongly bind together. After compacting, these final materials will be heated to a point below the melting temperature, thus creating a fine surface finish. This is the basic process of powder metallurgy.

3. Machining of Metal Matrix Composite

The machining of the metal matrix composites differ from the conventional ones due to the high strengths and wear resistive nature of the composite. The various machining processes are as follows.

3.1 High Speed Turning on the Composites

In this turning operations, different tools with various coatings and geometry angles will be used on Al2O3/Al metal matrix composite.

The different tools are

1. CVD diamond-coated carbide tool
2. Carbide coated tool
3. PCD diamond inserted tool
4. CVD diamond inserted tool

Turning tests were performed on a numerically controlled vertical lathe which has spindle speeds to reach 5000 rpm. With tool lead angle $\chi=90^0$ and Inclination angle of $\lambda=0^0$ side rake angle=5^0, back rake angle=0^0, side cutting-edge angle=0^0, and end cutting-edge angle=3^0. The machining was done gradually by measuring the tool wear and also the surface roughness of the composite is measured.

The final results after the operations were, Flank wear plays a more important role in determining the tool life. It is being observed that, for a given removed material volume, minimum flank wear is achieved with a particular combination of low cutting speed and relatively high feed, but for diamond coated tools, much higher wear resistance and the minimum for the flank wear is achieved at higher cutting feed and speed. The higher wear resistance of the coated tools is due to the higher abrasion resistance of the diamond coatings with respect to the carbide. The faster wear rate of the CVD diamond insert can be reduced by securing stronger adhesion between the diamond coating and the carbide substrate. The effects of localised forces and thermal load cause the coating to be removed along a line parallel to the cutting edge.

3.2 Electro Discharge Machining

This process is very slow. EDM results in a crater-like surface. The size of the crates increases with increased discharge energy. EDM produces a relatively small amount of sub-surface damage on the cut surfaces. The separated workpiece during EDM is removed in different ways such as side flushing, electrode injection flushing and electrode suction flushing. When we machine aluminium composite with the EDM, the challenges faced are

1. The high melting point of AL composite
2. High electrical resistivity of the Al composite
3. Debris of Al falling into the Spark plug

Even with the high melting point and electrical resistant, Al composites can be machined with EDM process. The EDM process with a rotating hollow-tube electrode and optimised flushing pressure give good results.

3.3 Fluid Machining

The fluid can be used in two ways for machining the Al composite. First, to use the fluid as a single tool and other is to combine fluid with a metal tool.

Using fluid as the only tool, we get abrasive water jet machining. Here water is mixed with abrasive particles and concentrated onto the work piece as a pressurised flow jet. This has advantages like, no induce high temperatures and as a consequence, there is no thermally affected zone, furthermore since high feed rates are possible. The drawbacks are, a good surface finish can be achieved only when a low feed rate is given.

Using fluid along with a normal work piece. A normal machining process is done on the work piece, but in addition a pressurised flow of fluid is added alongside the work piece. The action of fluid had no effect on the tool wear but helped to clear the chip formation on the work piece.

3.4 Laser Machining Process

Laser machining offers significant productivity advantages for rough cut-off applications. It is apparent that a laser is very suitable for high feed rates and can produce a cut with a narrow kerf width. Reinforcing the aluminium matrix with SiC ceramic particles improves the machinability of the composite, due to the reduction in the optical reflectively of the material.

Laser machining can also be used for the bending process also. This is called laser forming, where laser forms a metal sheet by thermal residual stresses instead of external forces. No rigid die is necessary and any three-dimensional geometrical shape in principle could be obtained by a proper path of a laser beam. This is suitable for the shaping of hard and brittle composites that are difficult to form by conventional methods. In the case of aluminium composite, the bending angle increases linearly with the number of irradiations and decreases gradually with increases in the processing velocity.

4. Summary

When is the machining process of metal matrix composites is considered, the can be done with conventional methods used upgraded tool such PVD(polycrystalline diamond coating) coated tools have low wear rate and CVD(Chemical vapour decomposition) diamond coated tools have a better removal rate than the conventional tools in machining composites. While considering the un-conventional machining techniques EDM process required high current inputs to the machine but can be machined efficiently with optimal flush rate. Laser beam machining creates high temperatures while machining and also has a better removal rate compared to other techniques. Abrasive jet machining, when used with appropriate abrasive material with respect to the composite, has good removal rate and gives good surface finish when operated at low feed rates. This summarizes the efficient techniques of manufacturing and machining of aluminium based metal matrix composites.

5. Conclusion

The data from the above study reveals that the manufacturing of the aluminium metal matrix composite is highly effective when calculative amounts of reinforcements are added and appropriate techniques are employed based on material design, such as Centrifugal casting is preferred for hallow structures while Squeeze casting is preferred for Complex structures. Laser beam machining for higher removal rate and abrasive jet machining for good surface finish.

References

[1]. L Zhuoxuan, S Xiandong, L Chengping, O Liuzhang. The Fabrication and Properties of Particle Reinforced Cast Metal Matrix Composites, Journal of Materials Processing Technology, 1997, 426-431.
[2]. A Gatto, L Iuliano, L Settineri. High-speed turning experiments on metal matrix composites, Composites, 1998,1501-1509.
[3]. BH Yan, CC Wang. The machining characteristics of Al2O3/6061Al composite using rotary electro-discharge machining with a tube electrode, Journal of Materials Processing Technology, 1999, 222-231.
[4]. NP Hung, SH Yeo, BE Oon. Effect of cutting fluid on the machinability of metal matrix composites, Journal of Materials Processing Technology, 1997, 157-161, 1997.
[5]. HY Feng, JE Caroline. Andrewes, WM Lau. Machining of an aluminum/SiC composite using diamond inserts, Journal of Materials Processing Technology, 2000, 25-29.
[6]. J Monaghan, F Mu¨ller. Non-conventional machining of particle reinforced metal matrix composite, International Journal of Machine Tools & Manufacture, 2000, 1351-1366.
[7]. KC Chan, J Liang. Laser bending of an Al6013/SiCp aluminium matrix composite sheet, Journal of Materials Processing Technology, 2000, 214-218.
[8]. PY Li, SL Dai, SC Chai, YR Li. High damping Al-Fe-Mo-Si/Zn-Al composites produced by rapidly solidified powder metallurgy," Scripta mater, pp. 955-960, 2000.
[9]. XP Zhang, GF Quan, W Wei. Preliminary investigation on joining performance of SiCp-reinforced aluminium metal matrix composite (Al/SiCp–MMC) by vacuum brazing, Composites, 1998, 823-827.
[10]. E Gervais, H Levert, M Bess. The development of a family of zinc-base foundry alloys, AFS Trans, 88, 1980, 183-197.
[11]. MPDHD Apelian. Casting with zinc alloys, J.of Mets, 33(11), 1981, 12-19.
[12]. E Gervais, RJ Barnhurst, C ALoong. An analysis of selected properties of ZA alloys, J of Mets, 37(11), 1985, 43-47.
[13]. S Muthukumarasamy, SY Buni, S Seshan. ZA-27 alloy-based cast MMCs with ceramic paticle reinforcment, AFS Trans, 112, 1994, 819-825.
[14]. AA Das, B Zantout, MM Yakoub, AJ Clegg. Squeeze casting of matel matrix composites, in Int. Symp. on ZA casting alloys. CIM, Toronto, 1986.
[15]. R Guerriero, JB Parse, I Tangerini. Metal matrix composites utilising Zn-Al alloys, Ibid, 229-247.
[16]. I Blain, I Masounave. A study of the dry abrasion properties of zinc-aluminium matrix; Fe, AI, AhO) particles composites, Processing of Ceramic and Metal Matrix Composites, 1989, 464-473.
[17]. HX Zhu, SK Liu. Mechanical properties of sqeeze cast zinc alloy matrix composites containing alumina fibres, Composites, 24(5), 1993, 437-442.
[18]. M. Popescu, S. Dionne, I Lo, F Goodwin. Particulate reinforced ZA-8 MMCs fabricated by stir casting and pressure diecasting, AFS Trans, 102, 1994, 665-671.
[19]. TD. Metal matrix composites applications and prospects," Metals and materials, 15, 1987,. 662, 1987.
[20]. AMS Hamouda, MSJ Hashmi. Mechanical properties of aluminium metal matrix composites under impact loading, Journal of Materials Processing Technology, 56, 1996, 743-748.
[21]. CHP Chadwik. Machining of metal matrix composites, Metals and Materials, 1990, 73-76.
[22]. RP Looney, JM Monaghan, PO'Really, Tap. The turning of an Al/SiC metal matrix composites, International Journal of Materials Processing Technology, 33, 1992, 453-468.
[23]. W Konig, R Fritsch, Kammermeier. New approaches to characterising the performance of coated cutting tools, Annals of the CIRP, 1, 1992, 49-54.
[24]. P Monaghan, O'Reilly. The drilling of an Al/SiC metal-matrix, Mater. Process. Technol, 33(4), 1992, 469-480.

[25]. J Soni. Microanalysis of debris formed during rotary EDM of titanium alloy (Ti 6Al 4V) and die steel (T 215 Cr12), Wear, 177(1), 1994, 71-79.
[26]. U Heisel, M Lutz. Investigation of cooling and lubricating liquids, Prod. Eng. USA, 1(1), 1993, 23-26.
[27]. MJ McGinty, CW Preuss. Machining ceramic fiber metal matrix composites, Proc. High Productivity Mach&mg Materials and Processes, USA, 1985, 231-242.
[28]. JE Allision, GS Cole. Metal matrix composites in the automotive industry opportunities and challenges, J Min. Met. Mater, 45(1), 1993, 19-24.
[29]. JT Lin, D Bhattacharyya, C Lane. Machinability of a silicon carbide reinforced aluminum metal matrix composite, Wear, 181, 1995, 883-888.
[30]. S Barnes, IR Pashby, DK Mok. The effect of workpiece temperature on the machinability of an aluminum/SiC MMC, Trans. ASME, Manuf. Sci.Eng, 1996, 1996, 422-427.
[31]. KA Fenoughty, A Jawaid, IR Pashby. Machining of advanced engineering materials using traditional and laser techniques, J. of Mat. Pro. Tech, 42, 1994, 391-400.
[32]. T Le Roux, MLH Wise, DK Aspinwall. The effect of electro discharge machining on the surface integrity of an Aluminium–Silicon carbide metal matrix composite, an Aluminium–Silicon carbide metal matrix composite , 3, 1993, 223-241.