EXPERIMENTAL INVESTIGATIONS OF MACHINABILITY OF AL MMC AND RELATED TOOL WEAR

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Abstract: This is a review paper.Metal matrix compositions (MMC) have become a leading materials and particles reinforced aluminum MMCs have received considerable attention due to their excellent mechanical properties like high hardness, high tensile strength etc. As with traditional materials it is important to understand the wear mechanisms that contribute to tool wear which reduces tool life. The objective of this research is to evaluate the machinability characteristics for these hard to machine materials MMC.

INDEX TERMS Metal matrix composites, machining parameters, wear mechanisms, hard to machine material, tool life.

I. Introduction

Metal matrix composites (MMCs) are a relatively new category of composite materials that consists of a ductile metal matrix reinforced by strong particles, fibers or whiskers [1-3]. Common matrix metals include aluminum, titanium, magnesium, cobalt, copper and various alloys of these materials. The reinforcement material is generally a brittle ceramic material; typical examples include silicon carbide (SiC) and boron carbide (B4C), and more recently, TiC [4, 5]. MMCs are increasingly desirable for their improved specific properties which combine the toughness and ductility of the metal matrix phase, with the hardness and strength of the reinforcement phase [6, 7]. To increase the demand for MMCs used for aerospace machined products, though as yet require a full explanation of several of the unique machining properties of MMCs which remain unsolved. Certain characteristics of MMCs [8] during cutting have given rise to conflicting reports which generally agree that MMCs are very difficult to machine [9].Research into improving or quantifying the machinability characteristics of MMCs has been undertaken.

MMCs have in recent times become commonplace in the aerospace and performance automobile industries [10], where the high cost of machining the material can be afforded. However, a wider product base using MMCs has been extensively reduced by the difficulties associated with the material's machinability [4]. The conventional single-shear plane cutting models are unsuitable for modeling the cutting process of MMCs during machining [11]. Very few attempts have been made into generating predictive models for the behavior of MCs during the machining process [12-15]. Further study into the prediction of the machining forces and machining parameters is required to fully understand the behavior of the material [16-19].

A. Effect of tool selection

The majority of studies were conducted on lathes, with the next favored machine tool being the vertical mill. In addition to milling there were some drilling operations being examined [20]. The recommended twist drill used was normally PCD diamond coated. However, many studies contend that carbide tools are a suitable alternative under certain conditions [21]. This is especially useful since carbide tips are cheaper, and tool wear starts relatively quickly, allowing different parameters to be examined to determine their suitability. This is obviously ideal for examining cooling methods in determining if the onset of the wear mechanisms has been slowed down or not. The studies revealed that carbide tools were used 53% of the time, compared to other materials, and from the papers surveyed coated or uncoated carbide tips were evenly used. Studies into the feasibility of high speed steel (HSS) and ceramic tools have found them both to be unsuitable for MMC applications [21-23], as ceramic tips are brittle and HSS wear too quickly. However, TiN coated HSS tools can be economic for short run production [24] and twist drills. Cubic boron nitride (CBN) has also been investigated as a potentially viable tool material. Testing however indicates that PCD tools are more appropriate [25-27] and is the most suitable tip material for production purposes.

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a. **Cemented Carbide Tools**

The feasibility of using cemented carbide tools to machine MMCs is a point of contention among the scientific community. Many researchers have suggested that cemented carbide tools are not suited to the machining of MMCs by many researchers [28-30]. A number of conflicting studies have concluded that carbide tools are useful for machining MMCs under certain conditions [31-33]. Carbide tools have been found to be effective in short run machining operations [34, 35] or for roughing operations [36]. It has also been proposed that they perform with industrially acceptable tool life at low cutting speeds (20-30 m/min) and high feed rates when machined using a lathe [23]. Certain carbide tools at cutting speeds of 250 m/min have been observed with a tool life of 40 min when lathe machining Al-SiC based composites [37]. Hung et al. performed investigations into various tooling types and concluded carbide type tools to be the most economical method for machining MMCs [38].

b.Polycrystalline Diamond Tooling

Polycrystalline diamond (PCD) tools have been used for the machining of MMCs for many years with much success [53-58]. This success has been attributed to the fact that the hardness of PCD tool tips is greater than the majority of reinforcing particles and fibers that make up the reinforcement phase [59, 60]. There is a general consensus among researchers that the use of PCD tooling offers a significant increase in tool life over carbide tools, making it the ideal tool material for machining MMCs [55, 61-64]. The tool life of various tool materials as shown in Figure 3 clearly showed that PCD tools provided the longest tool life. A study by Chambers and Stephens [65] found that PCD tools were far superior to other tool types when machining an aluminum-based, 5% Saffil, 12% SiC material on a lathe.

While most studies have found that PCD tooling yielded an improvement in tool life, Chen and Miyake [66] noted that the improvement in tool life was far less than expected while testing an Al-Mg5 alloy reinforced with 20% Saffil on a lathe. The life of the tool was only doubled, in contrast to significant gains in tool life when machining conventional materials.

Chambers and Stephens [65] observed the primary wear mechanism while machining MMCs with PCD tools to be abrasion. Many other studies suggested that the wear observed was primarily abrasive [37, 39, 67, 68]. One study identified microchipping in a PCD tool and therefore concluded that increasing feed rate and depth of cut to maximize material removal rate (MRR) would be unsuccessful. This conclusion contrasts the findings from studies into carbide tool tips, which suggest maximizing these quantities to improve MRR over the lifespan of the tool. Increases in cutting speed have been shown to yield an increase in the rate of tool wear similar to that of carbide tools [69].

B.Cutting speed Radhika et al. used ANOVA to conclude that feed rate had the highest influence upon the surface roughness when machining MMCs [110]. Chandrasekaran and Devarasiddappa performed mill tests and used fuzzy logic in their analysis. They identified feed rate as the main contributor to surface finish and recommended minimizing it to improve the quality of the finish [111]. This suggestion is supported by Kilickap et al. and Srinivasan et al. [87, 112]. Multiple researchers have produced similar recommendations using ANOVA techniques on lathe tests [77, 96, 113]. A study into the sustainable machining of MMC material by Boswell et al. using milling tests supported the conclusion that feed rate was the primary influence on surface roughness, however the results of their testing found that surface finish improved with an increase in feed rate [33] which is contrary to conventional wisdom. Another study indicated that at low speeds, particle pull-out has a greater influence on surface roughness than the feed rate [114].

C.Effect of Feed Rate

Studies have shown that at higher feed rates, the rate of abrasive wear on the cutting tool decreases [100-103]. One of these studies attributes the decrease in wear to the thermal softening of the work piece material as interface temperature rises [23]. Lin et al. suggest that the feed rate will also make a significant contribution to the thermal softening of the tool material [104]. Another study suggests that the decrease in wear at

high feed rate is caused by the reduction of contact between the tool tip and the abrasive particles of the dispersed phase of the material [105]. Studies have also shown that the effect of feed rate is not as significant as cutting speed upon the usable tool life [68 106]. A study performed using a lathe by Pendse and Joshi found feed rate to be the primary influence upon surface finish [107].

D.Effect of Cutting Depth

The majority of studies into the machinability of MMCs have yielded corresponding results as to the effects of the depth of cut. Turning studies by Rabindra and Sutradhar suggest that an increase in depth of cut yields an increase in total resultant cutting force [115]. Several quantitative analyses using methods such as ANOVA on completion of lathe tests have suggested that the depth of cut has the least significant effect upon the rate of tool wear and the quality of the machined surface finish [68, 77, 96, 111, 116]

E.Effects of Coolant Selection

During the machining of traditional materials, tool life and surface finish issues are helped by using coolant to reduce friction and for dissipating the generated heat. A variety of different cooling methods need to be investigated when machining MMCs, as each will yield differing results during machining. As metal matrix composites have developed into a commercially available material, several attempts have been made to determine a suitable method of cooling MMCs during machining, none of which have yielded results comparable to the cooling of traditional materials [127-129]. All of the more mainstream machine coolants that have been applied to traditional materials have been investigated thoroughly for their effects upon the machining of MMCs. Several more unconventional methods have not yet been investigated as a means for cooling MMCs during machining. The investigation of coolants for the machining of MMCs remains an important research topic, as researchers have yet to discover a truly effective method of cooling the heat generating zone of the tool.

II.CONCLUSION

This review has confirmed many of the difficulties experienced when machining MMCs using traditional machining techniques and processes, highlighting the need for careful selection of the machining parameters, tool type and method of cooling. These are the key elements for achieving an economical and accurate cutting process. The selected parameters affect the quality of the machine finish and the rate of wear of the tool tip.

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