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Influence of TiB_2 particles on machinability and machining parameter optimization of TiB_2/Al MMCs

Ruisong Jiang [a,*,1], Xinfa Chen [b,1], Renwei Ge [b], Wenhu Wang [a], Guodong Song [a]

[a] *The Key Laboratory of Contemporary Design and Integrated Manufacturing Technology, Ministry of Education, Northwestern Polytechnical University, Xi'an 710072, China*
[b] *China Academy of Engineering Physics, Mian'yang 621900, China*

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Abstract In situ formed TiB_2 particle reinforced aluminum matrix composites (TiB_2/Al MMCs) have some extraordinary properties which make them be a promising material for high performance aero-engine blade. Due to the influence of TiB_2 particles, the machinability is still a problem which restricts the application of TiB_2/Al MMCs. In order to meet the industrial requirements, the influence of TiB_2 particles on the machinability of TiB_2/Al MMCs was investigated experimentally. Moreover, the optimal machining conditions for this kind of MMCs were investigated in this study. The major conclusions are: (1) the machining force of TiB_2/Al MMCs is bigger than that of non-reinforced alloy and mainly controlled by feed rate; (2) the residual stress of TiB_2/Al MMCs is compressive while that of non-reinforced alloy is nearly neutral; (3) the surface roughness of TiB_2/Al MMCs is smaller than that of non-reinforced alloy under the same cutting speed, but reverse result was observed when the feed rate increased; (4) a multi-objective optimization model for surface roughness and material removal rate (MRR) was established, and a set of optimal parameter combinations of the machining was obtained. The results show a great difference from SiC particle reinforced MMCs and provide a useful guide for a better control of machining process of this material.

1. Introduction

Particle reinforced metal matrix composites (PRMMCs) have emerged as an important class of materials for aerospace and some other applications due to their superior properties such as higher strength to weight ratio, high elastic modulus and wear resistance.[1,2] Typically, PRMMCs can be prepared in two ways, which are called ex situ and in situ process respectively. In ex situ process, the reinforcements are synthesized

* Corresponding author.
E-mail address: jiangrs@nwpu.edu.cn (R. Jiang).
1 Those authors contributed equally to this work.

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separately and added in the matrix by a secondary process such as stir casting. The segregation of reinforcement particles and poor adhesion at the interface are normally observed in ex situ composites.[3,4] On the contrary, the in situ composite involves synthesis of reinforcing phases directly within the matrix, which leads to a better adhesion at interfaces and hence improves mechanical properties.[5]

Concurrently, most researches focus on the material preparation process[6] and the mechanical properties[7,8] of in situ particles reinforced MMCs. However, for engineering applications, adequate knowledge for machining these high performance materials is necessary. It is well known that the reinforcement particles embedded in the matrix are highly abrasive. This makes the machining of MMCs difficult, and the difficulties primarily are rapid tool wear and poor surface quality.[9] Since the preparation process of ex situ MMCs is much easier, SiC particles reinforced MMCs are widely used in industry practice. Hence, most studies have dealt with the machinability of SiC particles reinforced MMCs in tool wear[10–12], surface integrity[12–14], and chip formation.[15,16]

On the other hand, very little work has been done on the machining of in situ MMCs. Ding et al.[17,18] studied the grinding behavior of TiC_p/Ti-6Al-4V MMCs (PTMCs). They found that PTMCs are more difficult to remove than Ti-6Al-4V, and low depth of cut and high workpiece speed are beneficial for a better surface quality. Further, the performance of electroplated CBN wheel and that of brazed CBN wheel were compared, and it was found that brazed CBN wheel has greater potential in high-speed grinding of PTMCs according to experimental results. Anandakrishnan and Mahamani[19] investigated the machinability of in situ Al-6061-TiB_2 MMCs. The effects of cutting parameters on tool wear, cutting force and surface roughness were analyzed. The relationship between TiB_2 reinforcement ratio and tool wear, surface roughness, and cutting forces were achieved. Senthil et al.[20] studied the machinability characteristics of homogenized Al-Cu/TiB_2 in situ metal matrix composites. The effects of parameters on performance measures were investigated during turning operations, and the built-up edge and chip formation were also examined. Siva et al.[21] developed a new in situ ceramic reinforced aluminum metal matrix composite, and the machinability of this new AMC was investigated by comparing with two other composites made with Al_2O_3 and Al_2O_3-SiC. Jiang et al.[22] carried out experimental investigation on the machinability on TiB_2/Al MMCs. Tool wear, surface quality, and chip formation were discussed. It was found that PCD tool sustained the least tool wear compared to PCBN and coated-carbide tools. Xiong et al.[23,24] studied the surface integrity and tool wear mechanisms of TiB_2/Al MMCs. The main tool wear mechanisms are abrasion, adhesion, chipping, and peeling wear. Tool life is various from 3 to 20 min for uncoated carbide tools, and milling speed has the dominated influence.

Besides, in engineering practice, selection of cutting conditions for MMCs is the most critical job in machining operation. Palanikumar and Karthikeyan[25] investigated the influence of machining parameters on the surface finish obtained in turning LM23 Al/SiC particulate composites, and the optimum machining conditions for maximizing the metal removal rate and minimizing the surface roughness were determined using response surface methodology (RSM). Also, Palanikumar et al.[26] optimized machining condition for minimizing the surface roughness by using desirability function approach. Sahoo and Pradhan[27] presented the influence of process parameters like cutting speed, feed and depth of cut on flank wear and surface roughness in turning Al/SiC_p metal matrix composites using uncoated tungsten carbide insert in dry environment. The optimal parametric combination for flank wear and surface roughness was achieved through Taguchi approach.

Additionally, some researchers dedicated their effects on the optimization of cutting parameters by using soft computing. Muthukrishnana and Davim[28] studied the surface roughness of Al-SiC(20_p) by using PCD insert under different cutting conditions. The experimental data were tested with analysis of variance (ANOVA) and artificial neural network (ANN) techniques. Ramanujam et al.[29] presented the detailed experimental investigation on turning Al/SiC MMCs using PCD insert. The correlation between cutting speed, feed and depth of cut to the specific power and surface finish on the work piece was established. The optimum machining parameters were obtained by Grey relational analysis. For in situ particles reinforced MMCs, Kishore et al.[30] studied the effect of process parameters such as cutting speed, feed rate and depth of cut on response cutting force, surface roughness, and flank wear during turning process of in situ Al6061-TiC metal matrix composite. Moreover, Kishore et al.[31] investigated the contribution of cutting speed, feed and depth of cut on cutting force and surface roughness of Al6061-TiC by using Taguchi L-27 orthogonal array and ANOVA.

From the above analysis, it can be found that a lot of work has been conducted on the machinability and cutting parameter optimization of ex situ SiC particles reinforced MMCs. However, different microstructures between ex situ MMCs and in situ MMCs result in different mechanical properties. Consequently, the machinability of in situ MMCs will be different from ex situ MMCs, but only a little work has been conducted on the machinability and cutting parameter optimization of in situ MMCs. In addition, machining efficiency is also an important index for industrial applications.

To address the problems above, this study try to achieve a better understanding of the effects of reinforced particles on machining forces, residual stress, and surface roughness with varied cutting parameters when TiB_2 particle reinforced MMCs specimen is machined. Moreover, based on the experimental results, a multi-objective optimization model was proposed to get optimal machining parameter combinations by considering material removal rate and surface roughness. The organization of the paper is as follows: Section 2 discusses the detailed conditions of the machining trials. In Section 3, the experimental results are presented and discussed. In Section 4, the multi-objective optimization model is established and optimized by using GA algorithm. Finally, conclusions and future work are given in Section 5.

2. Experiment

2.1. Material and specimen

The materials used in this experiment were non-reinforced 7050 aluminum and the same alloy reinforced with 6 vol% TiB_2 (The size of TiB_2 particles varies from 50 to 200 nm) particles using the mixed salts method. The nominal chemical composition (wt%) of the matrix alloy is shown in Table 1.