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A study on the machining characteristics of induction and laser-induction assisted machining of AISI 1045 steel and Inconel 718

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ABSTRACT

Difficult-to-machine materials are being widely used in various industries. However, these materials are much more difficult to machine using conventional machining (CM) methods than other common materials, because of their superior material properties such as high strength, stiffness and brittleness. Thermally assisted machining (TAM) methods have been developed to address this problem. Laser assisted machining (LAM) is a type of TAM process in which a workpiece is locally softened by a laser heat source in front of the cutting tool. The method is an effective way to enhance machinability when processing various difficult-to-cut materials. Two other approaches, induction assisted machining (IAM) and laser-induction assisted machining (LIAM), were analyzed and experimentally investigated in this study to compare their efficiency with that of CM for two materials, AISI 1045 steel and Inconel 718. It was found that cutting force was decreased and surface quality was improved when the IAM and LIAM were used.

1. Introduction

Thermally assisted machining (TAM) is an economic, rapid-heating heat treatment technique for enhancing the machinability of materials. TAM has been used extensively in industry for various applications over the past few decades, and has been widely investigated by researchers. TAM is mainly applied to difficult-to-cut materials which cause high machining cost by conventional machining (CM) methods. Shin et al. performed TAM of titanium alloy and nickel alloy. The cutting force was reduced by about 20% compared with the CM, and the tool wear was also reduced. In addition, machining costs such as laser, tool, tool exchange and operation costs were decreased by about 30–50% compared to CM [1,2]. They performed thermal and mechanical modeling analysis for micro machining using TAM on three difficult-to-cut materials. The reliability of the analysis model was verified by comparing the simulation results with the experimental results [3]. Some researchers conducted the TAM using various heat sources to verify the effectiveness of the TAM. As a result, machining characteristics such as cutting force, specific cutting energy, tool wear and surface roughness were enhanced by TAM [4–7]. Recently, Ito et al. has applied TAM to precisely machine a glass. The surface roughness was reduced by 74%. The tool life was shortened, but the glass was precisely machined by TAM [8]. Lee et al. successfully machined the specimens with the three-dimensional shape such as cylindrical and spherical shape using the TAM and a new preheating method was proposed to improve the preheating effect [9–11]. By using heat to soften the metal workpiece prior to machining, TAM can reduce the energy used for cutting materials by reducing the amount of force which needs to be applied to the workpiece. Among the various TAM processes, the laser assisted machining (LAM) process locally softens a workpiece using a laser heat source. Induction assisted machining (IAM) is also an effective TAM method. IAM is a non-contact process which requires no physical interaction with the metal material. An induction heat source can be used for preheating, welding, heat treatment, melting, etc. [4,12,13]. Also, the induction heat source can be replaced at a cost of about one tenth of the laser heat source, and the quality of induction heating can be superior to that of a laser heat source because the heating can be applied more evenly to the metal surface in various manufacturing methods [4]. In this study, the use of multi-heat sources (laser-induction) is proposed for the first time in TAM. The laser produces a narrow and deep heat affected zone (HAZ), and the induction produces a wide and shallow HAZ. Therefore, when using laser-induction, the disadvantages of a single heat source can be supplemented and the material removal rate (MRR) can be improved as the HAZ increases. In addition, low output lasers can be used by using the high output induction with low cost. Therefore, it is possible to reduce initial costs by using the low cost laser with low power, and it is possible to achieve equal or better machining efficiency as compared with the use of high power laser. The use of

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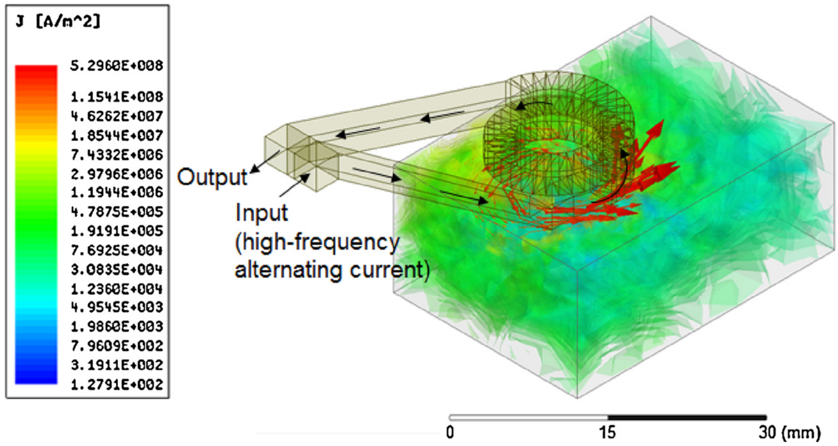

Fig. 1. Current distribution of material.

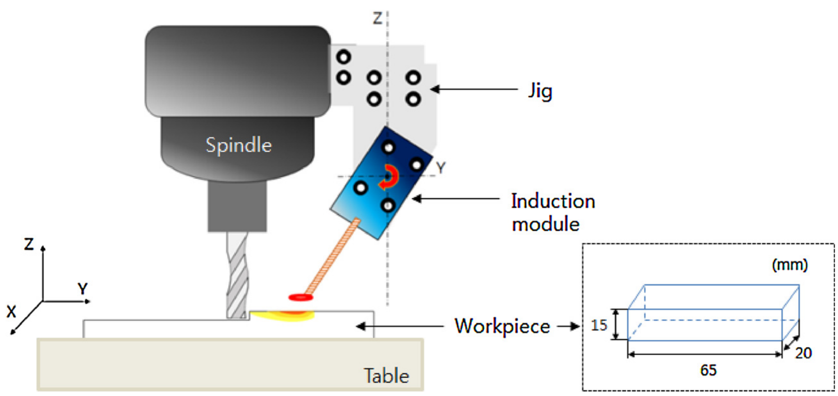

Fig. 2. IAM of workpiece with flat shape.

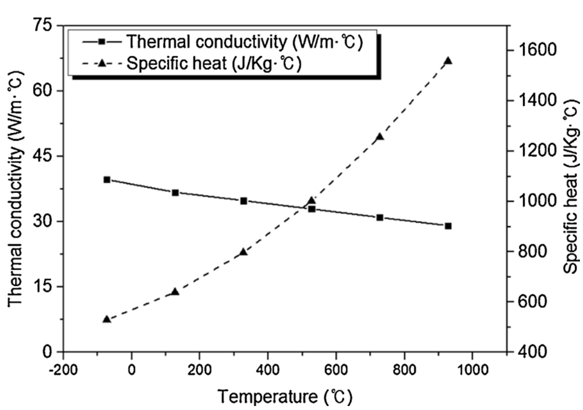

Fig. 3. The thermal conductivity and specific heat with temperature change of AISI 1045 steel.

multi-heat sources such as laser-induction is an important study to improve productivity and machining efficiency.

The number of TAM and manufacturing processes, using various energy sources, has been increasing because they efficiently facilitate the processing of difficult-to-machine materials [12–19]. Among various approaches that have been investigated, Dong et al. [20] conducted a coupled thermal-mechanical analysis using the finite element method (FEM), and compared experimental results to those from the analysis. Zhang et al. [21] compared CM with LAM for the Al/SiCp composite. The shape of the chip was saw-tooth and semi-continuous type, and there was no difference between CM and LAM, but the cutting force and shear zone stress decreased as the temperature of specimen increased. Vijenda et al. [22] studied a hybrid friction-stir welding process. The plastic materials were welded following induction heating of the tools, and various experiments were analyzed. As the tool-pin temperature by induction heating increased, the hardness of the joint center decreased and the joint efficiency increased. The optimal condition of hybrid friction-stir welding was derived from the conditions of maximum strength of joint (a tool-pin temperature of 45 °C and a rotational speed of 2000 rpm). Wiedenmann et al. [23] investigated process modeling with experimental validation. Cutting force and tool wear were analyzed using the developed model, and the results demonstrated the superior quality of the laser assisted milling. Bermingham et al. [24] studied wear mechanisms and tool life during laser assisted milling. Their study investigated machining methods and parameters such as dry conditions, flood coolant, minimum quantity lubrication (MQL), laser assisted milling and hybrid laser + MQL milling. Jankowski et al. [25] analyzed the induction heating of solid cylinders for an approximate analytical solution. Song et al. [26] studied coupled electro-magnetic and induction heating. Their experimental results confirmed the predicted excellent temperature distribution in