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Research Paper

A study on the machining characteristics of specimens with spherical shape using laser-assisted machining

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HIGHLIGHTS

- Laser assisted machining (LAM) of specimens with spherical shape is performed.
- Contouring preheating method is proposed for the experiment.
- Specimens of AISI 1045, Inconel 718 and titanium alloy are used for the experiment.
- The depth of cut for the experiment is determined by finite element analysis.
- Effectiveness of LAM is verified by comparing with the conventional machining.

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ABSTRACT

Materials such as nickel-based alloys have high strength and excellent resistance to many corrosive environments, and are widely used in various industrial fields, but are difficult to machine using conventional machining. To machine difficult-to-cut materials, thermally enhanced machining (TEM) has been developed internationally. One of the currently applied thermally enhanced machining methods, laser assisted machining (LAM), uses laser preheating to locally soften materials ahead of the cutting tool before machining. There have been no research works by LAM for three-dimensionally shaped specimens. Compared to a plate shape, it is more difficult to predict the optimum LAM preheating temperature for a three-dimensional shape, because with a 3D surface, the shape of the preheated spot changes continuously during machining. In this study, LAM was applied to spherical shaped specimens of three different materials, AISI 1045, Inconel 718 and titanium alloy for three dimensional machining. Before the machining experiments, thermal analysis was carried out by finite element analysis (FEA) to determine the optimum preheating temperature. A contouring machining method was used in the experiments. Cutting force and surface roughness were measured to analyze machining characteristics, and were found to be improved by LAM. These results can be applied to similar machining of difficult-to-cut materials.

1. Introduction

With the increasing use of difficult-to-cut materials such as nickel-based alloys and titanium alloy in various industrial fields, methods of machining these materials are being widely studied. Such materials have high toughness and high-temperature strength, which makes them difficult to machine [1–6].

One method that has been applied to machine these difficult-to-cut materials, thermally enhanced machining (TEM) uses external heat sources to heat and soften the workpiece locally in front of the cutting tool. One of the thermally enhanced machining techniques, laser assisted machining (LAM), is a method that softens the difficult-to-cut material by laser preheating, which then makes it possible to machine. Researches on this machining method have been actively performed [7–11].

Jeon et al. [12] investigated how external energy enables the machining of hard to cut materials and improve the quality of machining. They found that preheating with a laser made the processing of the material possible (regardless of the difficulty of the processing) and proved more effective at providing better processing quality than traditional methods.

Jung et al. [13] analyzed the thermal deformation caused by laser heat and cutting heat during LAM using a finite element analysis. Singh et al. [14,15] studied the effect of laser and cutting parameters on cutting forces and surface finishing when cutting heat treated steel. They also analyzed the characteristics and predicted the heat-affected zone caused by laser heating in laser-assisted micro-machining. Kim and the present author [16] proposed experimental equations to predict cutting force and preheating temperature. Kang and the present author [17] proposed the

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exponents of a constitutive equation using experimental results and a thermal analysis based on finite element analysis.

Njiri et al. [18] developed a fuzzy logic algorithm for optimizing the feed rate by controlling the peak cutting forces. Brecher, C. et al. [19] introduced a new LAM process method by inserting a laser into a spindle, and performed a machining process of Inconel 718 using it. Zamani, H. et al. [20] performed a 3D simulation and machining experiment with Ti-6Al-4V using a carbide tool and proved the reduction of cutting force using LAM. Also, they confirmed increases in tool life. Ding et al. [21] examined increased workpiece temperature due to the laser heating and temperature variances in the cutting zone using a 3D prismatic thermal model. Navas et al. [22] reviewed works in the literature about the reduction in yield strength and the improvement of machinability by LAM. Cha et al. [23,24] studied the optimum machining conditions and the machining characteristics of silicon nitride with spline members in laser assisted turn-mill (LATM). Woo and the present author [25] analyzed the machining characteristics of AISI 1045 and Inconel 718 workpieces according to up-cut and down-cut milling in LAM. Wiedenmann et al. [26] developed a novel processing strategy and investigated cutting forces and tool wear by LAM. Bermingham et al. [27] studied the tool life and wear mechanisms of titanium alloy in laser assisted milling. Hedberg et al. [28] studied LAM of a Ti-6AL-4V (Ti-64) workpiece with the consideration of surface integrity.

This study examined the prediction of preheating temperature, and obtained an effective depth of cut for the laser assisted machining of specimens of three materials, AISI 1045, Inconel 718 and titanium alloy with spherical shapes, for three dimensional machining, performed here for the first time. Previous studies have investigated the two-dimensional plate shape. However, it is more difficult to predict the preheating temperature of a three-dimensional shape than a plate shape because the shape of the preheated spot changes continuously during machining. Thermal analysis by finite element analysis (FEA) was carried out to obtain the preheating temperature and effective depth of cut. Machining characteristics were analyzed by laser assisted machining experiments. A contouring machining method was applied for the experiments. The machining characteristics, i.e. cutting force and surface roughness, of circular arc machining were investigated for various spindle speeds in this study. Also, it was confirmed in this study that the spindle speed is an important machining parameter, especially for laser assisted machining. These results were analyzed to provide guidelines on machinability for three dimensional laser assisted machining.

2. Finite element analysis

2.1. Thermal analysis

Figure 1 shows the methods of preheating for specimens with spherical shapes. In the contouring preheating method, the laser heat source is maintained as a circular heat source because the angle between the workpiece and the laser module is constant. On the other hand, in the ramping preheating method, the laser heat source is changed because the angle between the workpiece and the laser module is changed according to the position of the laser module. Also, in the case of the ramping machining it is difficult to machine spherical shapes because the tool path is shortened at the side position of the spherical shape as shown in the following Fig. 2. The contouring preheating method was used to obtain a uniform preheating temperature distribution. This study focused on circular arc machining on 3-D spherical shapes rather than linear machining. When machining through a circular arc path, it is difficult to control the laser heat source because the laser heat source softens the material prior to the cutting tool. An additional axis that controls the laser heat source should be added to the laser heat source. There

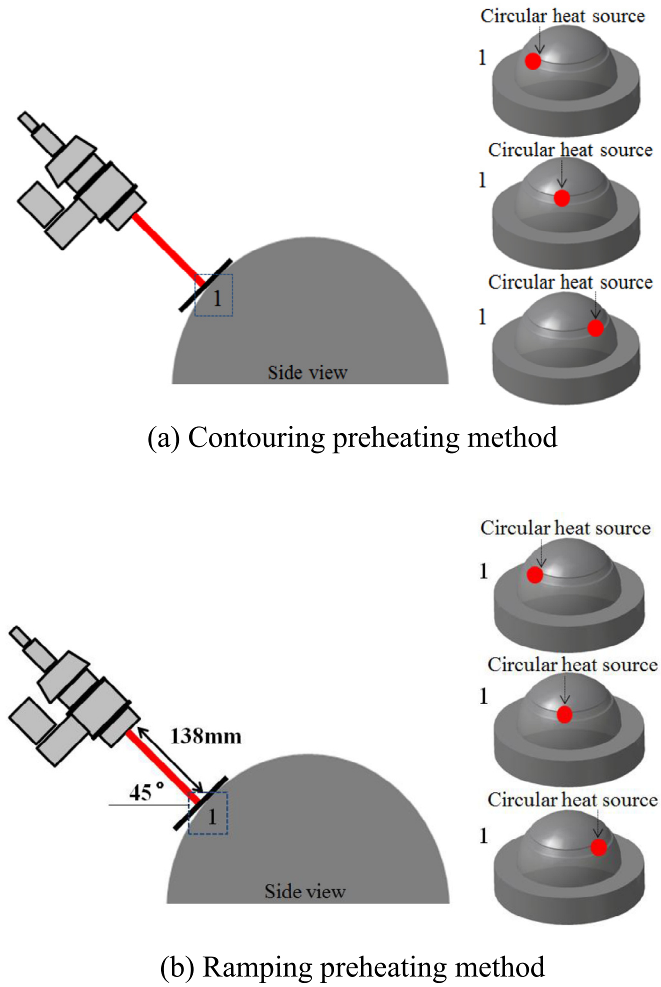

Fig. 1. Methods of preheating method in specimens with spherical shape.

have been few studies on circular arc machining on flat workpieces because of the difficulty in laser heat source control.

There are two machining methods, zig-zag and one-way, for machining specimens with a spherical shape. In zig-zag machining, although the return time of the tool is not needed, the machining accuracy deteriorates due to tool deflection. Conversely, although the return time of the tool in one-way machining is required, the

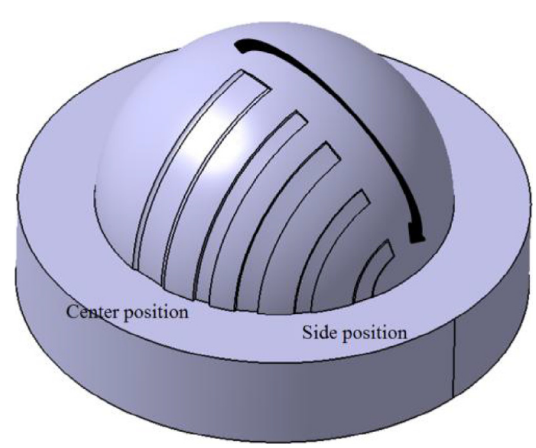

Fig. 2. The tool path according to position.