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Procedia CIRP 63 (2017) 324 – 329

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The 50th CIRP Conference on Manufacturing Systems

Dexterous Machining of Unstable Thin Plate

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Abstract

In recent years, miniaturization and light weightedness are required for industrial products as well as high functionality. Thin plates are appropriate in terms of weight, however they are usually difficult to produce only by cutting operation due to the deformation by cutting force or vibration of the thin plate. This study deals with the machining of a twisted thin plate, whose height, width and thickness are 50 mm, 30 mm and 0.1 mm respectively, without using any auxiliary tool. Such a thin plate with high aspect ratio is easily broken down by the cutting force. Thus, the machining of thin plate with high aspect ratio is approached by devising a tool path strategy in this study. As the cutting force easily allows for deformation of twisted thin plate with high aspect ratio, two methods are devised with regard to the generation of the tool path, the method with a supporting frame and the peeling method so that the stiffness of the plate can be kept high. Then, the actual machining of thin plate with high aspect ratio, made of aluminum alloy, was realized without any breakage. As a result, it is found that such cutting method allows the possibility of fabricating such a twisted thin plate.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems
Keywords: : Dexterous machining, Twisted thin plate, High aspect ratio

1. Introduction

Modern industrial products with complicated shape consist of a number of simple parts and elements to realize their function. These parts and elements must be manufactured whilst considering inter-compatibility between them. Products are commercialized by combining them with each other. However, in craftworks, the compatibility is not considered, and the complicated shape is often processed as it is by a skilled person. The skilled person copes with such craftworks by making use of innumerable know-how such as the cutting condition suitable for the machining, the fixture of materials, the preparation for special jig and tool, etc. Know-how owned by skilled persons is often thought to be implicit knowledge. If such an implicit knowledge, for example, the know-how such as the fixture of materials and the cutting condition, could be converted to explicit knowledge that can be expressed as an algorithm and technological procedure, it may be possible to produce the products and parts with highly added value like craftworks.

Such machining is called "Dexterous Machining" [1], which can be categorized into four areas as follows,

(1) Machining very complicated shapes [2] [3] [4]
(2) Machining extremely difficult-to-grip/maintain work-pieces
(3) Machining very hard/soft materials [5,6]
(4) Machining very unstable shapes

This study deals with the machining of easily deformable thin plates as part of the "Dexterous Machining" theme.

The turbine blade-shape has high aspect ratio of 500 with twisted plate, as shown in Fig. 1. Thus, the breakage of the thin plate may take place due to the deformation by cutting force and forced vibration.

In the study, two machining methods are proposed to create such a thin plate by using a multi-tasking machine tool [7]. One is to complete the workpiece shape by giving a supporting frame surrounding it and by removing a supporting frame from a workpiece shape after machining. The other is to machine the thin plate like peeling the down words from the upper part.

It is expected that accurate machining can be carried out by these two methods, while suppressing the workpiece

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2017.03.321

deformation and the chatter vibration, without decreasing stiffness of the thin plate workpiece.

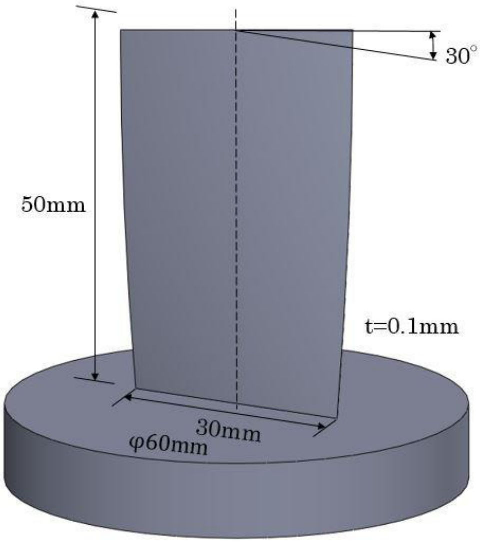


Fig. 1. Example of unstable shape like turbine blade.

2. Machining method with supporting frame

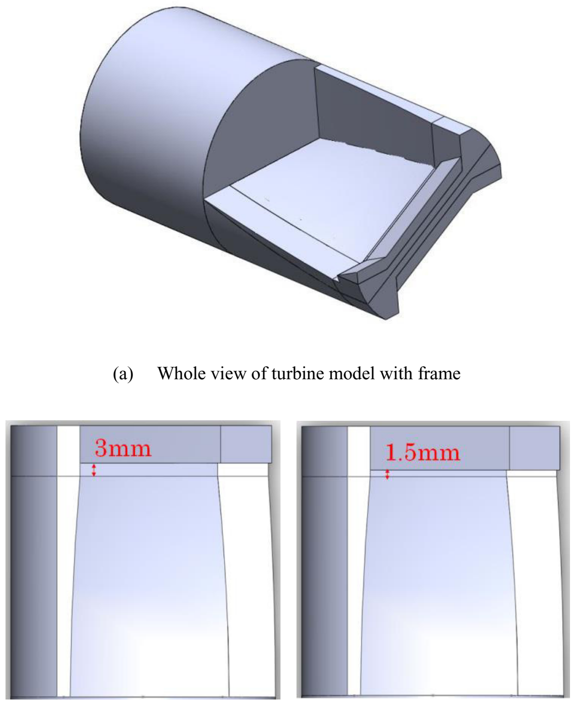
2.1. Outline of machining method

Let us introduce how to add a supporting frame to the workpiece. In making a thin unstable shape with a high aspect ratio, the portion near the root is better machined than the other end in terms of the form accuracy and the surface finish. It is because the portion near the root has increased stiffness. The supporting frame is added in 3D CAD system, taking account of the following two conditions;

(a) The supporting frame can be cut off from the finished thin plate.

(b) The supporting frame must be added so that the cutting tool can machine the thin plate, while keeping the tool attitude inclined by 30 degrees to both sides against the feed direction, in order to reduce the amount of bending of the thin plate.

Figure 2 shows the shape satisfying the above conditions. To confirm the effectiveness of the supporting frame, analysis by use of Solidworks Finite Element Modelling (FEM) was performed regarding the models with and without the supporting frame. The deformation and strain of the models are compared under the condition that the cutting force is applied at the tip of the thin plate from the direction normal to the plate surface by 30 degrees. The plate thickness is assumed to be 1.3 mm, considering the plate thickness of the rough finishing. The analysis conditions are listed in Table 1. The material used in the simulation and cutting experiment is aluminium alloy A1060, the properties of which are also listed in Table 1.



(a) Whole view of turbine model with frame

(b) Front view (c) Back view

Fig. 2. The turbine blade with frame.

Table1 Analysis Conditions

Maximum element size	0.60 mm
Tolerance	0.03 mm
Load	5 N
Workpiece Material	A1060
Young's modulus	$6.9e^{10}N/m^2$
Poisson's ratio	0.33
Density	$2700kg/m^3$