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Effect of Layer Thickness on Natural Frequency of the Adhesively Bonded Steel Disc Structure

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Abstract. The effect of adhesive thickness on the vibration features of the steel disc was investigated by the modal analysis, buckling analysis and static analysis based on the practical application. The results from the elasto-plastic finite element analysis show that the natural frequency of the structure is increased as the thickness of the adhesive layer increased. The low-order vibration is mainly shown as plain round or less pitch vibration mode. The critical load is affected by the location of the load applied. The deformation occurred in the disc structure is much more serious at the load point than the point which is far away in the axial direction. And the deflection of the adhesively bonded 65Mn steel disc is increased with the adhesive thickness increase.

Introduction

In practical cutting, the resonance between the natural frequency of the circular saw blade and the exciting frequency due to cutting force fluctuation also causes the lateral vibration of the circular saw blade [1]. Demir and Mermertas [2] investigated the natural frequencies of annular plates with circumferential cracks using finite element method. Tahani et al [3] developed a semi-analytical method for the analysis of deformation and three-dimensional stress field in rotating annular disks made of cylindrically orthotropic nested rings. Caner and Bazant [4] studied mechanical properties of sandwich structure. Jing et al [5] investigated the deformation and failure modes of dynamically loaded sandwich beams using the experimental method. In recent years, the applications of the adhesive are much more widely [6].The goal of this work is to study the dynamic response such as natural frequency and critical load of the adhesively bonded steel disc structure.

Finite Element Model and Mesh

The 65Mn steel disc is shown in Fig.1 with the outer diameter 2R =230 mm and inner hole diameter 2r =22 mm and the thickness t = 1mm.The mechanical properties of the materials used in this study are listed in Table 1. To investigate the effect of the thickness of the adhesive layer, four thicknesses were taken into account as 0.05mm, 0.10mm, 0.15mm and 0.20 mm respectively. The element solid 45 was used to both metal disc and adhesive layer. The mapping rules were used to divide it into hexahedron mesh as shown in Fig.2.

Modal Analysis

The modal analysis with non-prestress was carried out to research the natural frequency of the structure in this work. As shown in Fig.2, the six freedoms in the inner hole are all restrained and it is solved with Block-Lanczos algorithm. The effect of adhesive thickness on the natural frequency of the disc structure is shown in Fig.3. It is clear that natural frequency becomes higher with the thickness increase while the stiffness increased. That means the effect of adhesive thickness is evidently on the natural frequency and principal modes. The first-ten mode shapes of the adhesively bonded steel disc structure with the layer thickness of 0.1mm are shown in Fig.4. It is shown that the natural frequency of the 1st-order is the same as that of 2nd-order (118.145 Hz) but the mode shape is orthogonal to each other. And the similar couples are found as 4th-order with 5th-order, 6th-order with 7th-order and 8th-order with 9th-order. It is obviously that the nodal circle and nodal diameter of each order are (0, 1), (0, 1), (1, 0), (0, 2), (0, 2), (0, 3), (0, 3), (0, 4), (0, 4) and (2, 0) when it is fully-constrained at the center hole.

Table 1 Mechanical property of the materials

Materials	Elastic Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Tang Modulus (MPa)
65Mn	208	0.3	325	2000
Phenolic resin	2.875	0.42	90	500

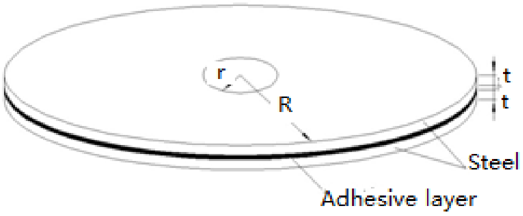

Fig.1 Finite element model

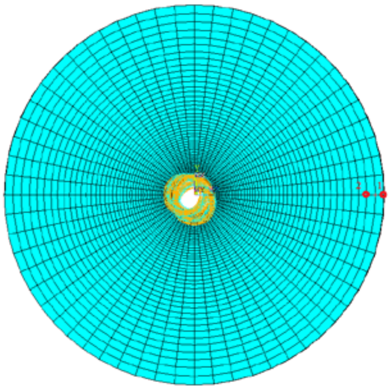

Fig.2 Finite-element meshes for steel disc.

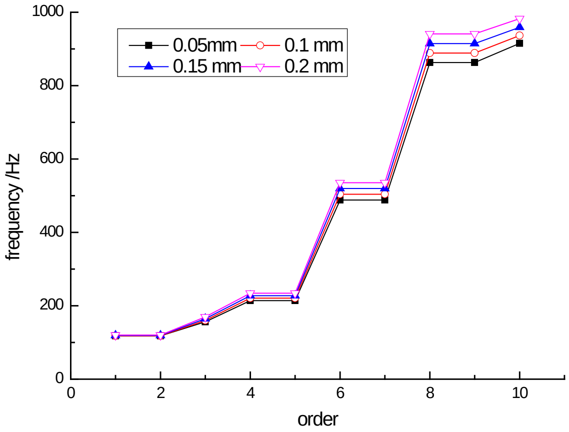

Fig.3 Natural frequency with thickness and order.

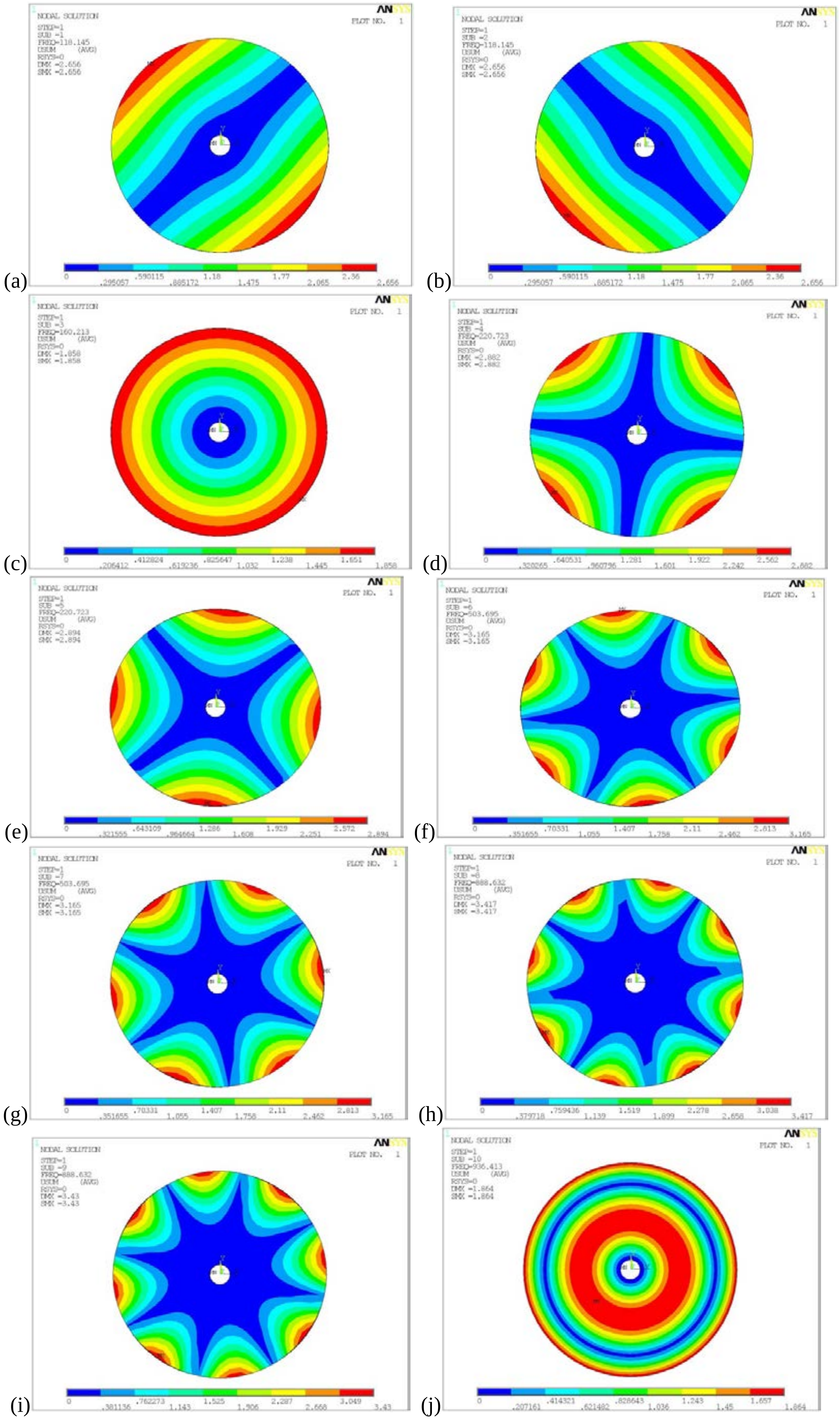

Fig.4 First 10-order mode shape of the adhesively bonded steel disc with the thickness of 0.1mm.(a)1st-order, (b)2nd-order, (c)3rd-order, (d)4th-order, (e)5th-order, (f)6th-order, (g)7th-order, (h)8th-order, (i)9th-order, (j)10th-order,

Eigenvalue Buckling Analysis

The Eigenvalue buckling analysis is the main method of structural stability for its computation efficiency. The results from bucking eigenvalue analysis can be used to predict its academic buckling load and obtain the buckling critical load of the structure so that it is useful to guide the real project. A unit load is applied on node 1 (Fig. 2, outside the plate edge) along the direction of radial and node 2(Fig. 2, radial 110mm) in the axial direction respectively. The results from eigenvalue buckling analysis are shown in Tab. 3 and it is clearly that the critical load is increased with layer thickness increase when the load id acted at node 1. While setting the initial load at node 2, the biggest critical load appeared when the thickness is 0.1mm. It may be determined the suitable adhesive thickness in the practical application according to loading situation of the structure.

Tab.3 Eigenvalue buckling critical load (N)

location of load	adhesive thickness			
	0.05mm	0.1mm	0.15mm	0.2mm
1	3983.5	4165.2	4363.3	4570.5
2	7457	11311	11210	10882

The Deformation under a Force along the Axial Direction

The load applied to the structure was taken as 30N on node 2 perpendicular to the disc along the axial direction. The deformation from the analysis is shown in Fig.5 where 0 and 360 corresponding to the edge of the cylindrical on the radius at the point the load is applied on. The deformation is mainly demonstrated in the axial direction. The deformation at the nodes near the load point is much more than that of the further one. The deflection of the steel disc increases as the adhesive thickness increase. It is easier to cause the fatigue failure under the cyclic loading.

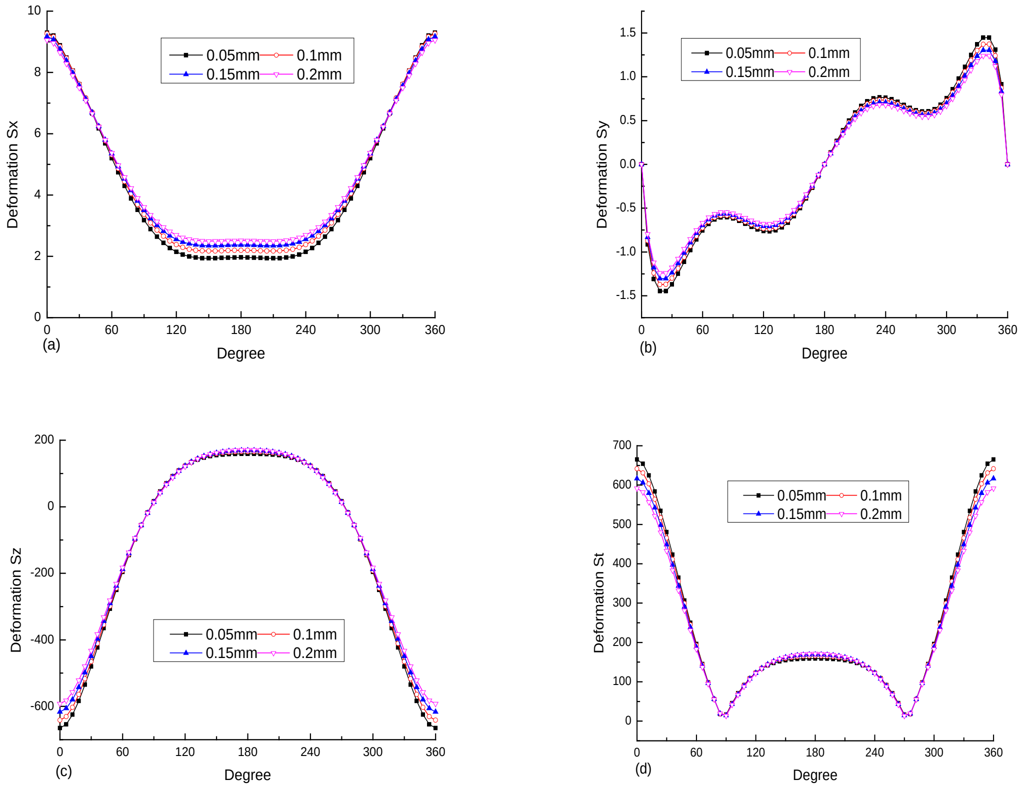

Fig.5 The effect of the adhesive thickness on the deformation around disc along three directions as well as the sum: (a) Sx; (b) Sy; (c) Sz and (d) St. (unit: μ m)

Summary

The results from the elasto-plastic finite element modal analysis show that the effect of the thickness of the adhesive is evidently on both the natural frequency and principal mode of the adhesively bonded steel disc. The natural frequency becomes higher when the thickness is increased. The lower vibration modes of the structure are mainly no quarter circle or less pitch circle. The results from the eigenvalue buckling analysis indicate that variation tend changed due to different load location. Under the condition of the investigation, it is suggest that the layer with 0.1 mm thickness be suitable for the practical application. The deformation at the nodes near the load point is much more than that of the further one. The deflection of the steel disc increases as the adhesive thickness increase.

Acknowledgements

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