Design of anodic alumina nanostructure for adhesive interface through stress–strain simulation

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In the automotive and aircraft industries, where weight reduction is required, adhesion between the metal and resin is one of the most important technologies. One way to achieve strong adhesion between the metal and resin is to increase the chemical-bonding force and anchoring effect at the interface by creating a nanostructure on the metal surface. In a previous study, we constructed anodic nanostructures on an aluminum surface and systematically investigated the chemical-bonding force and anchoring effect. [1] We found that the shape of the pores, such as depth and diameter, is a factor that determines the magnitude of the anchoring effect. However, because this shape was a straight hole, only the frictional force on the side of the hole appeared as anchoring effect. By constructing a hole shape with a larger hole at the root, it is expected that a hooking force will be generated and greater adhesive strength will be obtained. At present, there are some reports of anodic oxidation with a larger hole shape at the root, but the adhesive strength of this structure has not yet been clarified. [2] In this study, we use simulation to evaluate the anchoring effect of anodic alumina as a parameter of the nanostructure.

To discuss the anchoring effect, a finite element method (FEM) simulation was performed using ANSYS software. Figure 1 illustrates the model used in the simulation. It consists of a quarter-symmetrical model of an aluminum hole shape filled with adhesive (epoxy resin; the density, Young's modulus, and Poisson ratio were set to 1100 kg/m^3, 3 GPa, and 0.38, respectively). The minimum diameter was set to 60 nm, whereas the maximum diameter was set to 70 and 80 nm. The tensile force was set to 20 MPa. The frictional forces acting on the interface were ignored to focus only on the hooking force.

Figure 2 shows the shape and stress distribution under tensile force. As the maximum diameter increased, the amount of deformation of the adhesive decreased, whereas the maximum stress value increased, implying that the anchoring effect was enhanced, and the possibility of the occurrence of the cohesive-fracture mode was increased against the interface-fracture mode. This result can be explained by an increment in the amount of deformation required for the resin to exit the hole shape that was caused by a larger maximum diameter.

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[1] K. Nagato, T. Yamaguchi, M. Nakao, *CIRP Annals*, 67 (2018) 595

[2] T. Yanagishita, H. Masuda, *AIP Advances*, 6 (2016) Article 085108

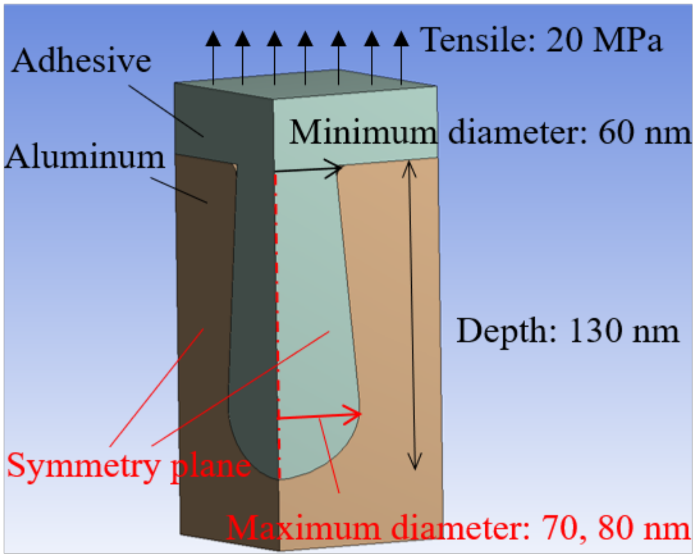
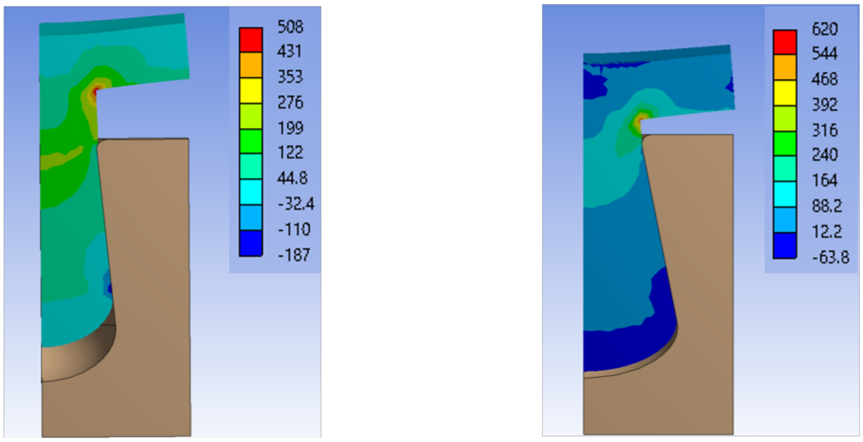


Figure 1: Schematic of FEM model.


(a) Maximum diameter: 70 nm

(b) Maximum diameter: 80 nm

Figure 2: Shape and stress distribution of adhesive with maximum diameter of (a) 70 nm and (b) 80 nm.