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Surface finishing method for tooth flank of heat-treated surface-hardened small gears using a gear-shaped tool composed of alumina-fiber-reinforced plastic

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ABSTRACT

High-accuracy gears are necessary to ensure the strength and silence of compact geared motors. Heat-treated surface-hardened small gears are employed in the reducer of a compact geared motor. The heat treatment causes distortion, which deteriorates the gear accuracy. To remove this distortion, surface-hardened small gears are rehobbed with a carbide hob. The rehobbing makes a tool mark on the gear tooth surface. This tool mark leads not only to strength deterioration of the tooth surface, but also vibration and noise. Therefore, a surface finishing method that eliminates the tool mark is required. However, it is difficult to finish surface-hardened small gears. This study proposes a tooth surface finishing method for a surface-hardened small gear. The method employs a gear-shaped tool composed of alumina-fiber-reinforced plastic (ALFRP) and a surface finishing device with an oscillation/traverse system. The proposed method was used in an experiment to remove the tool mark on the gear tooth flank of a surface-hardened small gear rehobbed by the carbide hob. The effectiveness of this method was verified. In addition, the processing mechanism of the ALFRP gearshaped tool was analyzed by observing the tool and the chips.

1. Introduction

Compact geared motors are used in devices such as medical equipment. Those devices are often installed in silent environments and are used near people, so it is desired that compact geared motors are compact, strong, and quiet. In order to satisfy these demands, high-precision gears are needed.

Compact geared motors use heat-treated surface-hardened small gears. However, the accuracy of these gears deteriorates due to heat treatment distortion [1]. This causes strength deterioration of the tooth surface as well as vibration and noise. Recently, due to improvements in gear machining technologies, it is possible to remove the heat treatment distortion of the gears after heat treatment by surface hobbing the gear teeth with a carbide hob [2–6]. Using this method, although it is possible to realize a certain degree of accuracy, the surface roughness deteriorates, as shown in Fig. 1, because the tool marks from hobbing remain on the gear tooth surface [7]. Therefore, a finishing process for improving the gear tooth surface roughness is required that can eliminate the tool marks on the surface. However, tool marks on heat-treated gears are difficult to eliminate because the tooth surface is hard. In the case of normal-sized gears such as automotive gears, a finishing process is performed on the gear tooth surface by a gear honing method with a gear-shaped grinding tool [8-11]. Therefore, this honing process also seems effective as a tooth surface finishing process for small gears. Actually, Karpuschewski et al. describe examples of finishing methods for heat-treated small gears using a gear-shaped grinding tool, although the details are unknown [11]. However, a gear-shaped grinding tool for small gears (module 1 or less) is difficult to manufacture with sufficient strength because the tool's teeth are too small compared with the abrasive grains.

In a previous report [12], the authors proposed a new gear-shaped tool that is made of alumina-fiber-reinforced plastic (hereafter called ALFRP) in order to remove nicks that are formed at the edges of surface-hardened heat-treated small gears. The report showed that the ALFRP gear-shaped tool has sufficient strength even if its teeth are small because fibers are used. In this study, the authors propose a new finishing process for the tooth surface of surface-hardened heat-treated small gears using an ALFRP gear-shaped tool. A new surface finishing device suitable for small gears is proposed that has an oscillation/traverse system. Experiments on the tooth surface finishing process using this device and the ALFRP gear-shaped tool are performed. It is verified that the tool marks on the tooth flanks of the heat-treated surface-hardened small

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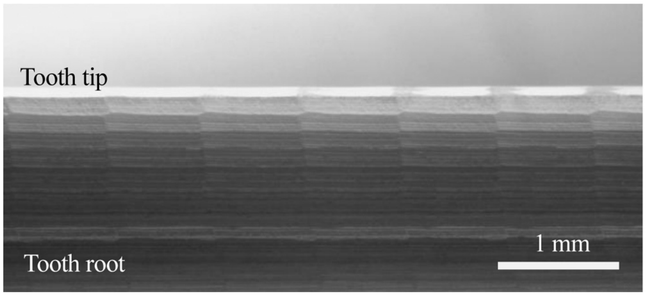

Fig. 1. Tool marks on tooth surface of work gear from hobbing.

gear can be removed, and the surface roughness of the teeth can be improved. In addition, the processing mechanism of the ALFRP gear-shaped tool is discussed by observing the surface of the tool and the chips in the cutting oil.

2. Characteristics of ALFRP and manufacturing method for gear-shaped tool

2.1. Characteristics of alumina long fibers and ALFRP

ALFRP is a compound material that is made by combining alumina long fibers with thermoset epoxy resin. The amount of fiber in the ALFRP used in this research is 60% by volume. As shown in Table 1, the tensile strength of alumina fiber with a diameter of 10 μm is 1.8 GPa. The Mohs scale of alumina fiber is 9, which means the hardness of the alumina fiber is the same as or more than that of hardened steel. For this reason, it is expected that ALFRP can be used in a removal tool for heat-treated surface-hardened gears. In addition, ALFRP has sufficient strength even if it is formed into small teeth on a small gear because alumina fibers are used. On the other hand, the hardness of ALFRP is not very high, so it can be machined using a cutting tool such as a carbide hob with a Rockwell hardness C-scale (hereafter called HRC) of 90. For this reason, it is possible to process ALFRP into a gear-shaped tool using a carbide hob. Thus, ALFRP is expected to function as a tool material for the tooth surface finishing of small gears and was chosen for this study.

2.1.1. Manufacturing method for ALFRP gear-shaped tool

First, prepregs with a thickness of 0.1 mm consisting of alumina fibers with a diameter of 10 μm are adhered together, and thin ALFRP boards with a thickness of 0.2 mm are made. Next, as shown in Fig. 2a, the thin ALFRP boards are laminated while changing the fiber direction by 45°. Therefore, when the laminated board is manufactured into a gear-shaped tool, the direction of some alumina long fibers is close to the direction normal to the tool tooth surface. For this reason, the tips of the alumina fibers appear on the tool tooth surface, and these function as cutting edges. Moreover, this stacking method helps to prevent breakage of the teeth on a small gear-shaped tool. A thick board of ALFRP is made by bonding the thin boards with thermoset epoxy resin by heating under pressure. A cylindrical disk blank is manufactured by cutting the thick board. ALFRP disk-shaped blanks used in this study are 40 mm in outer diameter and 10 mm in thickness. Finally, the ALFRP gear-shaped tool is made from the disk blank using a carbide hob and a hobbing machine. A manufactured ALFRP gear-shaped tool is shown in Fig. 2b. Fig. 2c shows the lamination state of the ALFRP, where the cross section of the ALFRP thick board is magnified.

3. Gear tooth surface finishing device with oscillation/traverse system

3.1. Principle

The principle of the gear tooth surface finishing process with an oscillation/traverse system proposed in this report is shown in Fig. 3. A work gear and an ALFRP gear-shaped tool are meshed in

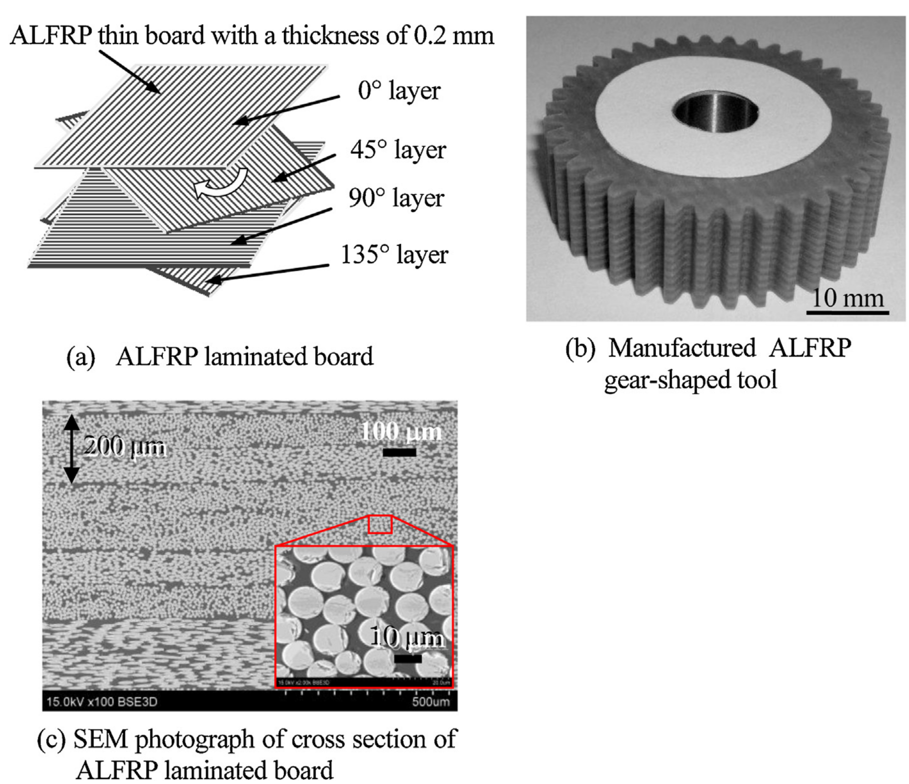

Fig. 2. Manufacturing method for ALFRP laminated board and manufactured ALFRP gear-shaped tool.