

Development of a low-distortion manufacturing process for large-diameter internal gears for e-Axles

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As e-Axles become smaller and lighter while achieving higher reduction ratios, their internal gears are becoming larger in diameter and thinner. This hollow, thin-walled geometry is highly susceptible to heat-treatment distortion because different regions cool at different rates, generating thermal stresses that affect circularity and tooth accuracy. Conventional correction processes are increasingly insufficient, especially because next-generation e-Axles require high gear accuracy to meet strict NVH requirements. This study investigated a low-distortion process that eliminates post-treatment correction by combining oil quenching with gas nitrocarburizing. Gas nitrocarburizing is performed at a lower temperature than carburizing and provides good wear and scuffing resistance through the formation of a hard iron-nitride compound layer. However, it produces a relatively shallow hardened layer and low core hardness, which can cause fatigue damage such as spalling in highly loaded gears. Oil quenching was therefore conducted beforehand to increase core hardness. A dedicated steel was developed by optimizing the carbon content for sufficient oil-quenched hardness and adding alloying elements to improve resistance to softening during gas nitrocarburizing.

Internal gears with an outside diameter of 140 mm were prototyped and compared with conventional case-hardening steel gears. Circularity and tooth accuracy were measured before and after heat treatment. The change in circularity was comparable to that of the conventional specification and remained acceptably small, while the change in tooth accuracy was smaller for the developmental specification. These results confirmed that the proposed process is particularly effective in reducing tooth-accuracy changes, which are difficult to correct in large, thin-walled internal gears. Cross-sectional hardness and microstructure were also evaluated. Although the developmental specification had a shallower hardened layer, it achieved higher surface hardness. Its dedicated material maintained sufficient core hardness through improved resistance to temper softening, providing the required spalling resistance. Wear and scuffing tests were conducted using a 100-mm outside-diameter helical gear with hardness and microstructure equivalent to those of the internal gear. The tests simulated severe lubrication conditions during full acceleration from rest in an EV reduction gear. The developmental specification achieved at least 1.2 times the scuffing resistance of conventional case-hardening steel, while wear after testing was approximately 5 μm . The iron-nitride compound layer likely suppressed direct metal-to-metal contact, while initial running-in may have reduced microscopic surface irregularities and local contact pressure. Thus, the combination of oil quenching, gas nitrocarburizing, and the dedicated steel composition established a low-distortion manufacturing process for large-diameter internal gears. It reduces tooth-accuracy changes, eliminates post-heat-treatment correction, and maintains the required core strength and spalling resistance. The process also improves scuffing resistance by at least 1.2 times and limits wear to approximately 5 μm , making it suitable for accurate, durable, and reliable internal gears in next-generation e-Axles.

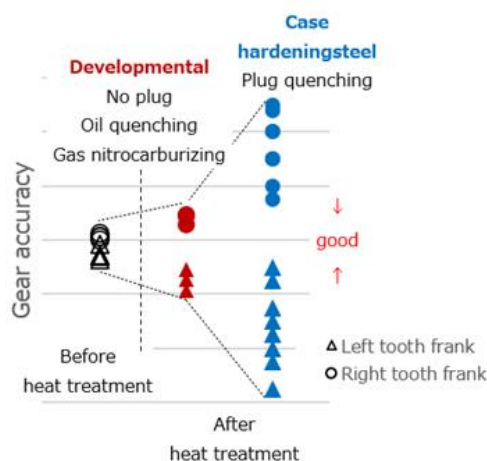


Fig. 1 Heat treatment distortion

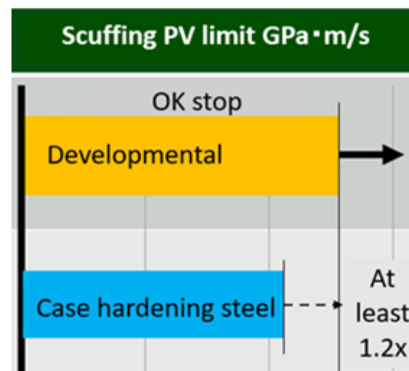


Fig. 2 Scuffing test results