

Fabrication of Thin Rotary Tools Through a Combination of Cross-Rolling and Austempering-Tempering

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Abstract. Production of thin rotary cutting tools involves several challenges related to the maximization of uniform tensile and bending properties and levelness. This research project investigates the feasibility of manufacturing these tools through cross-rolling and austempering-tempering of a high-carbon low-alloy steel. In this regard, the combination of the new deformation process and austempering-tempering was compared to a commercial circular saw blade made by conventional hot rolling followed by quenching and tempering. The results reveal that the cross-rolled austempered materials show higher resistance to tempering. They also show that the combination of cross-rolling and austempering-tempering results in higher: hardness (9%), yield stress (YS) (19%), UTS (%19), and bending strength (BS) (22%), while maintaining similar ductility when compared to the quenched and tempered material. The reason for such an improvement is related to the presence of homogeneous α and ϵ fiber textures in combination with a microstructure made of lower bainite. Tempering of bainite close to the bainitic transformation temperature range permitted to adjust strength/ductility and maximize the levelness of the final product. The novel manufacturing approach proposed enables the production of thinner rotary tools that minimize waste during the cutting operation.

Keywords: Cross-rolling · Austempering-tempering · Mechanical properties · Crystallographic texture

1 Introduction

Cross-rolling reduces the asymmetry of the mechanical properties along rolling (RD) and transverse direction (TD) by changing the slip systems and the Schmid factor [1]. Narayanswamy et al. [2] observed that cross-rolling strengthens the $\{100\}\langle 110\rangle$ texture of α fiber in the deformed sheets. Austempering (AUST) near the M_s temperature is reported to generate fine lower bainite and retained austenite (RA) having ultra-high strength (>2 GPa) and considerable toughness [3, 4]. The previous studies revealed that the original microstructure of the low-temperature bainite is retained during tempering [5, 6]. This phenomenon is more distinct for high-carbon steels [6]. The rotary tool-like

circular saws used for guided sawing applications should have excellent isotropic mechanical properties and perfect levelness [7]. The present study investigates the feasibility of manufacturing high-performance circular saws through cross-rolling and austempering-tempering (AUST-T).

2 Materials and Methods

High-carbon low-alloy steel plates (Fe- 0.70C- 0.60Si- 0.54Mn- 0.40Cr- 0.73Ni- 0.069Mo- 0.28Al (wt.%)) were cold-rolled to reduce their thickness from 5.3 to 2 mm (62% reduction). For one series of specimens, unidirectional-rolling (UR) was performed, while for the second one, cross-rolling (CR) was achieved by rotating the specimens by 90° after each pass. The Ms and Bs temperatures were calculated at 222 and 397 °C, respectively, using the MUCG83 software [8]. The sheets were austenitized at 860 °C for 30 minutes, followed by austempering at 250 °C for 1 hour. The austempered materials were clamp tempered at 400 °C for 2 hours. The microstructure and texture evolution were characterized through OM, FESEM, XRD, EDS, and EBSD. The hardness, tensile, and flexural properties were also measured and compared to a commercial saw manufactured from the same material through the quench and tempering (Q-T) process.

3 Results and Discussion

Figure 1 shows the microstructure of the CR AUST and AUST-T materials. AUST develops lath-like bainite and filmy RA (Fig. 1a). Tempering causes the coarsening of the microstructure and decomposition of RA to bainitic ferrite and carbide. The remaining RA is characterized by blocky and filmy morphology (Fig. 1b). Transformation-induced plasticity (TRIP) after AUST results in an ultra-high strength in the materials (Table 1). The CR samples showed higher resistance to softening than unidirectionally UR sheets during tempering (Table 1).

UR developed the $\langle 110 \rangle // RD$ and $\langle 111 \rangle // ND$ fibers and CR induced distinct $\{100\} \langle 110 \rangle$ texture of α and ϵ fibers (Fig. 2). The $\{100\} \langle 110 \rangle$ component of CR samples retained after AUST-T (Fig. 2). These components locate on the high-density

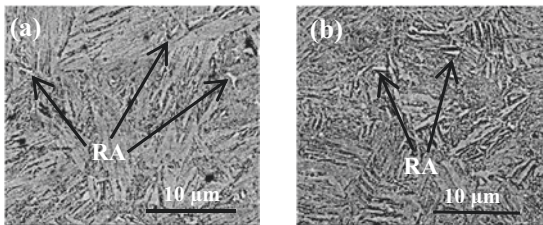
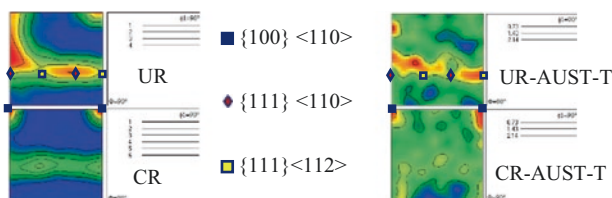


Fig. 1. FESEM micrographs of the CR AUST (a) and AUST-T (b) sheets etched with Nital.

Table 1. Mechanical properties of the AUST, AUST-T, and Q-T specimens.

Series identification	YS (MPa)	UTS (MPa)	BS (MPa)	Hardness (HRC)
UR- AUST	1822 ± 22	2308 ± 16	4434 ± 31	58.0 ± 0.4
CR- AUST	1836 ± 15	2304 ± 12	4511 ± 76	57.5 ± 0.5
UR- AUST-T	1488 ± 20	1626 ± 23	3076 ± 45	48.0 ± 0.5
CR- AUST-T	1586 ± 25	1740 ± 19	3386 ± 19	49.0 ± 0.6
Q-T	1331 ± 11	1477 ± 2	2777 ± 28	45.0 ± 0.3

**Fig. 2.** $\varphi_2 = 45^\circ$ ODFs of the rolled and AUST-T sheets.

110 planes resulting in uniform tensile behavior along perpendicular directions. However, UR sheets only have ductile behavior along RD. The intense texture of CR samples showed higher resistance to softening during tempering (Table 1).

4 Conclusions

Based on the above research, it can be concluded that: (1) AUST-T results in a bainitic microstructure with an excellent strength/ductility balance. (2) CR generates distinct uniform $\{100\}\langle 110\rangle$ texture, increasing material resistance to softening. (3) Production of thinner rotary tools with the same material is possible with CR and AUST-T.

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