

On-line Quenched and Self-Tempered High Strength Steels †

1. Introduction

Quenched and tempered carbon steel for machine structural use (e.g., S45C class) had been applied formerly as a steel material for construction machinery parts and other applications with similar requirements. Later, application of V-added quenched and tempered free steel was expanded with the aim of omitting the quenching and tempering process. However, in recent years, demand for low alloy (V-less) quenched and tempered free high strength steel has become increasingly strong in response to the sharp rise in the prices of V and other alloying elements.

Based on these circumstances, JFE Bars & Shapes developed a self-tempered type quenched and tempered free high strength steel (hereinafter, TQF[®] bar), with the aim of omitting the quenching and tempering process and realizing a low alloy product. With TQF[®] bar, quenching is limited to the surface of the steel material, and is performed with an on-line water cooling device installed at the Sendai Works Bar Mill.

The features of TQF[®] bar are introduced in the following.

2. Features of TQF[®] Bar

2.1 Outline of Manufacturing Process

The layout of the equipment at the Sendai Works Bar Mill is shown in Fig. 1. The reheating furnace is a walking beam type with liquefied natural gas burners. The rolling mill comprises a rough rolling mill (8 stands), intermediate rolling mill (8 stands), and finish rolling mill (2Hi type, 4 stands, 3-roll SCFM type, 4 stands). Cooling zones, comprising water-filled tubes, are installed following these rolling mills. TQF[®] bar is a steel bar product which is produced by on-line quenching of the surface layer, mainly using the product cooling device (⑩ in Fig. 1; 2 zones) installed after the finish rolling mill, and self-quenching by the retained heat in the interior of the material after it passes through the cooling device (Fig. 2). The main features of TQF[®] bar are as follows.

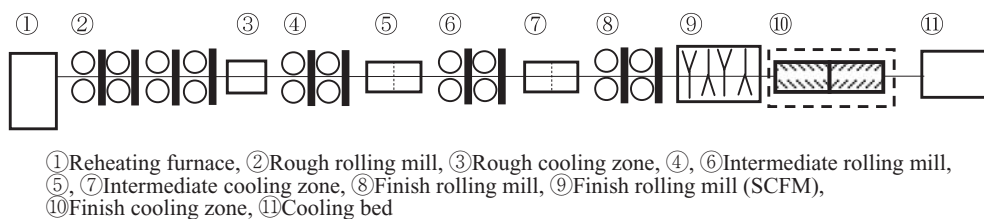


Fig. 1 Layout of rolling mill and cooling zone in bar product line

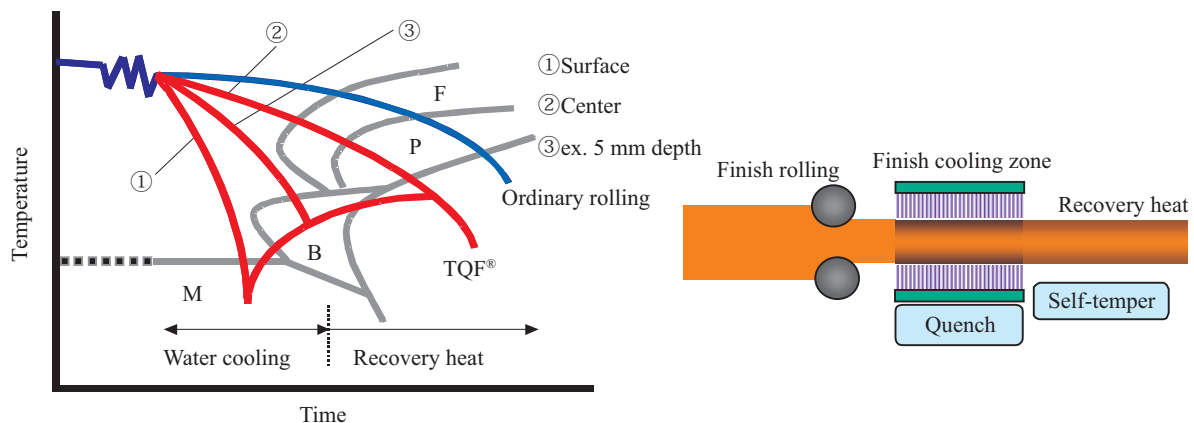


Fig. 2 Concept of material design for TQF[®] bar

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- (1) It is possible to reduce the contents of alloying elements because microstructure strengthening is used.
- (2) The strength and toughness of the bar product as a whole are improved because the surface layer forms a tempered martensite (or bainite) microstructure, and the interior forms a fine ferrite-pearlite microstructure.
- (3) The hardness distribution takes the form of a U-curve, resulting in improved fatigue strength and bending strength.
- (4) Induction hardenability is improved because the surface layer is a tempered martensite (or bainite) microstructure.

As the TQF[®] bar product line, products of 700 to 900 MPa class are being developed. Of these, the 700 MPa class is already in mass production up to a maximum size of 115 mm in diameter.

2.2 Example of Properties of TQF[®] Bar

The following presents an example of the properties of TQF[®] bar.

The macrostructure and microstructure of TQF[®] bar are shown in **Photo 1** and **Photo 2**, respectively. In the macrostructure, the darker area at the surface is the quenched layer. A uniform quenched layer without deviations has been obtained. The microstructure comprises

a tempered martensite microstructure in the surface layer (to a depth 5 mm from the surface in Photo 2), inside this ($D/8$), a microstructure consisting mainly of bainite, and further to the interior ($D/4$), a fine ferrite-pearlite microstructure.

The hardness distribution (**Fig. 3**) of the horizontal cross section displays a U-curve distribution corresponding to the cooling characteristics in the cross section and the resulting microstructures. The surface layer has high hardness and thus possesses excellent wear resistance, while the center has low hardness, securing high ductility and toughness. Together with having high fatigue strength and high bending strength in the entire round bar due to this U-curve shaped hardness distribution,

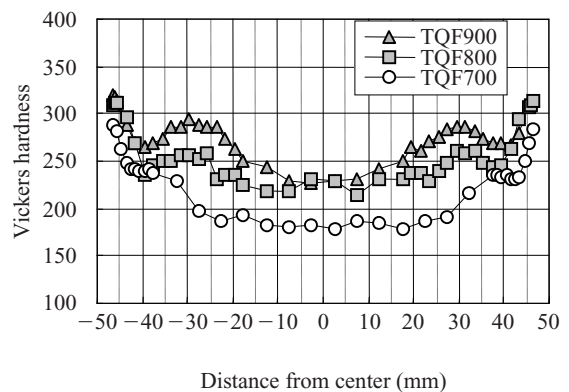


Fig. 3 Hardness curves of cross-section (φ95)

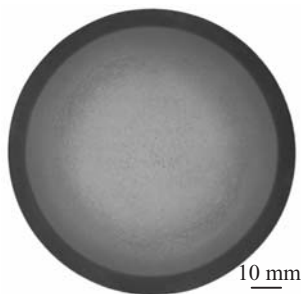
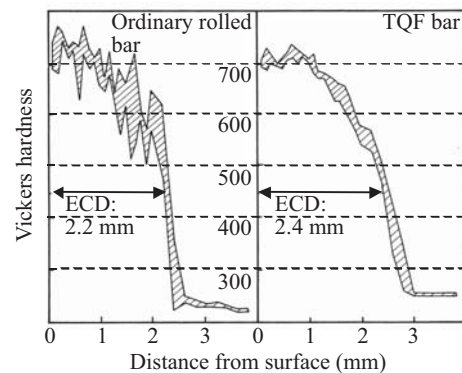


Photo 1 Macrostructure (φ95, TQF[®]700)



*ECD: Effective case depth

Fig. 4 Hardness curves after induction hardening

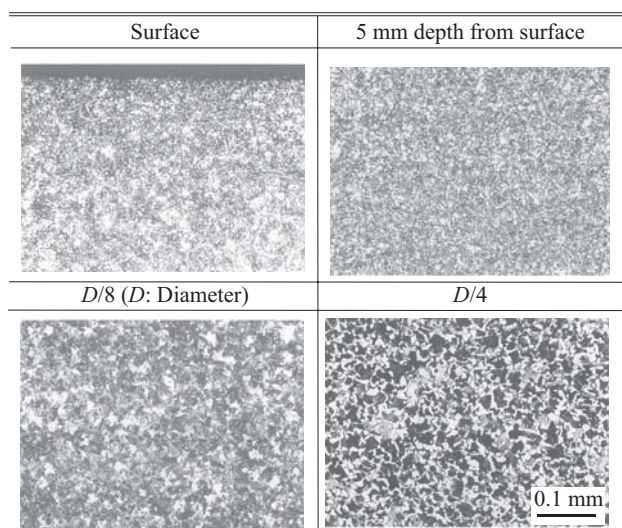


Photo 2 Microstructure (φ95, TQF[®]700)

Table 1 Mechanical properties of TQF[®] bars (φ95, V less steel)

Products	Strength class	Mechanical properties ($D/4$)				
		$\sigma_{0.2}$ (MPa)	TS (MPa)	EL (%)	RA (%)	uE_{20} (J/cm ²)
TQF700	700 MPa	467	746	23.6	46.7	66/over 105*
TQF800	800 MPa	515	839	22.1	59.3	45/105*
TQF900	900 MPa	601	931	18.2	52.3	13/65*

$\sigma_{0.2}$: 0.2% Proof stress TS: Tensile strength
 EL: Elongation RA: Reduction of area
 uE_{20} : Charpy impact value (U-notch, 20°C testing)
 * $D/8$

TQF® bar also has an excellent balance of strength and toughness.

Furthermore, because the surface layer of TQF® bar forms a tempered martensite microstructure, carbides can be dissolved in a short time during heating in induction hardening, and a uniform austenite microstructure is easily obtained. Thus, as an additional feature of TQF® bar, it is possible to obtain a stable quenched area with minimal deviations in hardness (**Fig. 4**). At present, TQF® bar is used as a substitute for quenched and tempered steel in hydraulic shovel pins, shafts, and piston rods, and other equipment with which induction hardening is used, taking advantage of these outstanding features. For reference, the mechanical properties of TQF® bar (dia. 95 mm) with a V-less steel composition are shown

in **Table 1**.

3. Conclusion

Amid strong demand for materials which contribute to reducing material costs and omitting processes, TQF® bar can be considered an optimal product for energy saving and process saving, based on its various distinctive features.

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