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Relationships between tensile and fracture mechanics properties and fatigue properties of large plastic mould steel blocks

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Abstract

Moulds for plastic automotive components such as bumpers and dashboards are usually machined from large pre-hardened steel blocks. Due to their dimensions, the heat treatment produces mixed microstructures, continuously varying with the distance from the quenched surface, at which fracture toughness and fatigue properties are not well known and generally lower than those corresponding to a fully quenched and tempered condition. The response of the mould to defects (for example, microcracks due to improper weld bed deposition) and stresses during service depends on steel properties, that in turn depend upon the heat treatment and the microstructure. A pointwise determination of the tensile, Charpy V-notched, fracture toughness and rotating bending fatigue properties was carried out in a large block. High cycle fatigue was investigated by the stair-case method. The samples were obtained from different depths of the blooms. The relationship between mechanical properties, fracture surfaces morphology and microstructure was also investigated.

Keywords: Plastic mould steel; Metallography; Mechanical properties; Fracture toughness; High cycle fatigue; Fractography

1. Introduction

Large forged steel blooms (typically 1 m × 1 m section and more than 1 m in length) are used to fabricate plastic moulds (Fig. 1a), in turn employed to form automotive components, such as bumpers and dashboards, made of thermoplastics, usually polypropylene or reinforced (ABS).

The stress patterns applied to the moulds in service arise from the polymer's injection pressure and from the local thermal gradients, and could be enhanced by notch effects and by defects of various origin (particularly weld bed depositions effected without the proper heat treatment that could be recommended for smaller components). Stresses may be significantly raised by abnormal operations, e.g., incomplete extraction of already formed objects.

Each mould is expected to produce a few millions of pieces in its life, corresponding to the production run of one car model; thus, fatigue effects should also be considered. Wear induced by the reinforced resins flow may be severe and may be an additional cause for crack nucleation and propagation, with the flowing resin infiltrating cracks and acting as a wedge.

For economic and logistic reasons, the traditional production cycle of mechanical components (rough machining, heat treating and finishing) has been abandoned and commonly substituted by machining pre-hardened blooms.

The most commonly used steel grade is 1.2738 (or 40CrMnNiMo8-6-4, ISO 4957 standard [1]), a heat-treatable, 0.4% C, high-hardenability, low-alloy steel (Table 1).

The section of the bloom is usually comparable to the section of the original ingot (because larger ingots are not feasible); thus, a sensible equivalent reduction ratio may be obtained only by repeated forging steps, each consisting of alternated elongation and compression cycles. The total deformation is much less than that obtained in rolling and not comparable in the effects,

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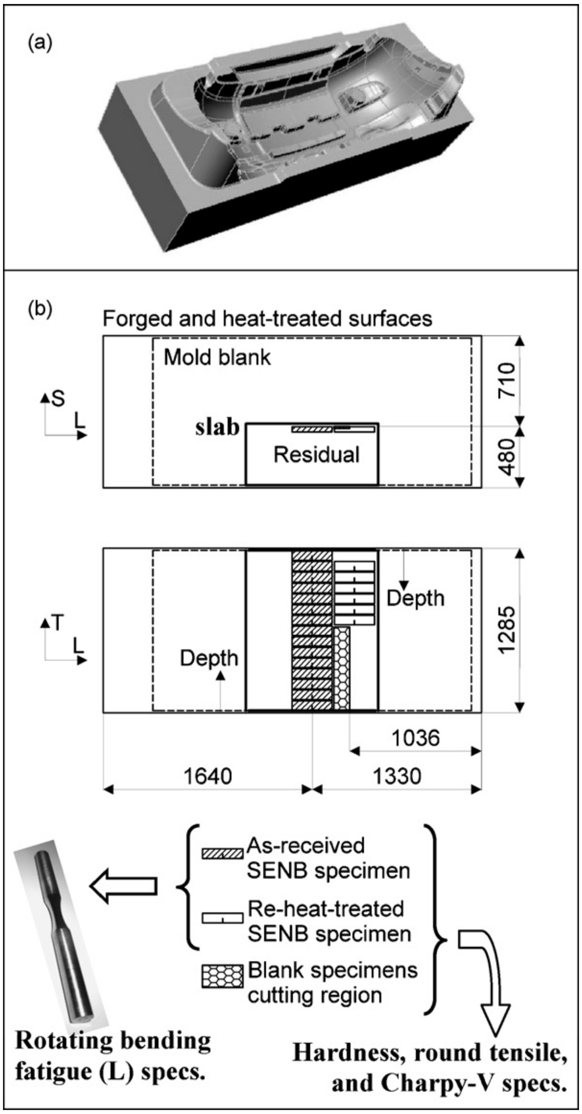

Fig. 1. View of half of an automotive bumper mold (a). Sampling plan to obtain 38 mm thick fracture toughness samples and smaller blanks cut at increasing depths inside bloom C (b).

because each step achieves only a limited reduction ratio (1.5 is a possible value).

Depending on the size, dehydrogenization can take a few days, whereas the durations of the austenitizing and tempering stages can be as long as 1–2 days. Usually, blooms are austenitized in the 840–880 °C temperature range, then quenched in oil and tempered in the 550–600 °C temperature range (more than one tempering stage may be applied) to obtain a final 330–300 HB hardness. Heating stages are usually executed in air.

Since forging yields a rough shape with deep decarburations occurring during heating, external material removal (usually performed in a commercial warehouse) may be up to 20 mm (plus scale). Furthermore, blooms may be sawn to requested size (often asymmetrically); blooms for bumper moulds are usually sawn to yield a U shape.

The dimension of the blooms exceeds the very high hardenability critical dimension of steel 1.2738 [2,3], thus in large oil-quenched blooms different microstructures occur at increasing depths, all of them being affected by the subsequent tempering.

The final mould shape is obtained in the mould-machining shop by chip-removal and/or electrical-discharge machining, followed by grinding with or without polishing in selected areas and by local surface treatments; upon request, shape corrections are performed also by welding additions.

Due to the sawing and machining operations, any of the microstructures occurring at different positions in the original bloom can be found at the mould face, where notch effects and welding thermal defects are often present. Previous studies have assessed the deleterious influence of the slack quench mixed microstructures upon the toughness of quenched and tempered low alloy steels [4,5]; nevertheless, whereas the fracture toughness of other tool steels was already studied [6–8], the same property for the above steel has been analyzed only recently by the authors, by considering its relationship with the different microstructures occurring inside the large blooms [2,9,10]. In the present work, these latter results (concerning not only fracture toughness, but also hardness, tensile properties and resilience) are summarized and completed by an investigation of the steel fatigue behaviour and an in-depth analysis of the fracture surfaces to assess the fracture mechanisms occurring in the different test-specimens.

2. Experimental

The examined bloom had the following original dimensions (after forging): 2970(L) × 1285(T) × 1190(S) mm. The L direction defines the long ingot casting and forging axis; properties in the S and T transverse directions are thought to be not differently influenced by the casting and forging procedures.

Series of 40 mm thick fracture toughness specimens and of smaller blank specimens were obtained at increasing depth from a slab cut as outlined in Fig. 1b.

The depth of a point is defined as its distance (in direction T) from the nearest forged and heat treated surface, or from a reference one. For fracture toughness specimens, depth is reported as that of the fracture initiation zone.

Specimens were tested either in the as-received or in a re-heat-treated condition.

The smaller blanks were used for metallography, Charpy-V, tension, and hardness testing; some of them were re-heat-

Table 1
Compositional limits for the plastic mould steel grade 1.2738 and heat chemical analysis of the examined bloom

	C	Cr	Mn	Ni	Mo	Si	S	P
Grade 1.2738–40CrMnNiMo8-6-4	0.35–0.45	1.8–2.1	1.3–1.6	0.9–1.2	0.15–0.25	0.2–0.4	<0.03	<0.03
Examined bloom	0.42	2.0	1.5	1.1	0.21	0.37	0.002	0.006