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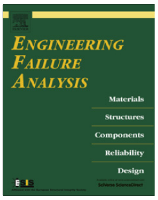

Hardness effect on thermal fatigue damage of hot-working tool steel

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ABSTRACT

Thermal cracks in die-casting are often caused by thermal fatigue loading, surface stresses, low material strength and surface irregularities. During the process cycle, alternate heating and cooling leads to thermal fatigue. Mechanical and thermal stress fluctuations initiate fine cracks on the cavity surface that grow larger and ultimately lead to failure of the die. Hardness or surface heat treatment can extend the die life time. The aim of this work is to study the thermal fatigue damage of AISI H13 tool steels that underwent different heat treatments. The results prove that the thermal fatigue resistance is closely related to the initial hardness. In fact, thermal fatigue tests prove that increases in the hardness of the steel lead to decreases in the crack growth rate. However, it seems that the heat treatment does any not major effect on the crack initiation period of thermal fatigue cracks.

1. Introduction

In hot metal forming applications, like stamping, rolling or die casting, the service life of the tools are limited due to their extreme working conditions in terms of thermal and mechanical (thermo-mechanical) loadings which result from the close contact between the tools and the hot workpiece (1200 °C for steel forging [1]) or the molten metal (675 °C for Al-alloy casting, 930 °C for Cu-alloy casting [2]). Under such working conditions, the tools are generally damaged through wear and thermal fatigue cracking processes [2–6].

The process of thermal fatigue damage during hot forming operations, results basically in alternating compressive and tensile stresses at the surface of the tools that arise from differential thermal expansion/contraction during sudden transient temperature changes [2,3,7].

During a complete metal forming cycle, the inelastic strain range achieved is straightforward dependent upon the temperature range (between the maximal temperature during heating and the minimal temperature during cooling) and the heating/cooling rates (transient thermal gradients) [2,3,7]. Under such working conditions, the surfaces of the tools are damaged through a process of non-isothermal low cycle fatigue. Surface damages arising from such process are actually usually denoted as thermal fatigue cracking or heat checking. Examples of typical surface damages observed on industrial tools are given in Fig. 1 for die-gravity casting applications.

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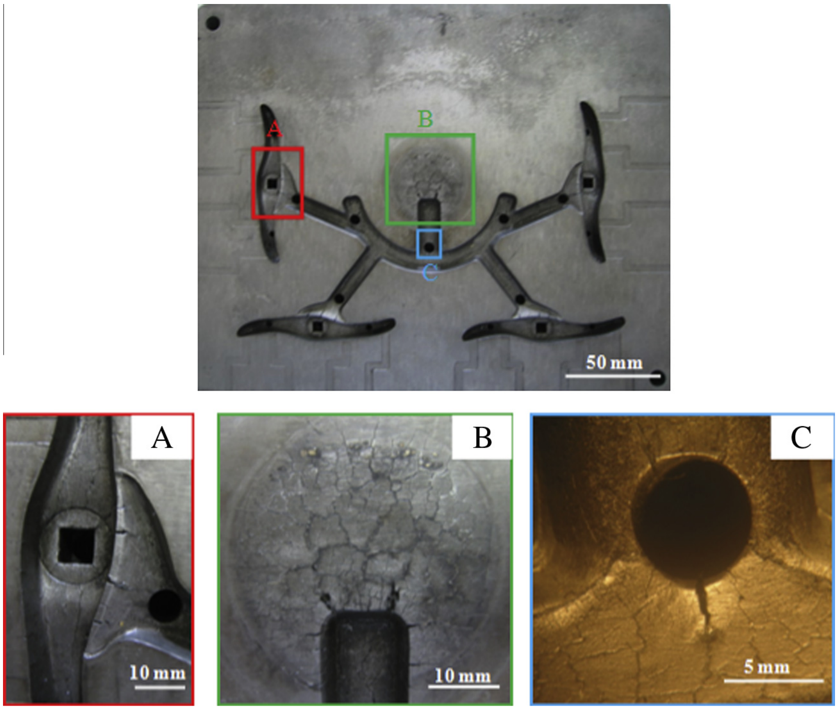

Fig. 1. Typical macroscopic surface damages observed on the different zones A, B and C on the casting die failures.

In addition to cyclic reversed plasticity, under long time operations and cyclic thermal transients, microstructural changes can occur altering the strength of the materials leading to the crack initiation and propagation [6]. Moreover, damage often involves oxidation, creep and fatigue interaction, so that coupled effects should be considered.

The surface damage of die casting dies was investigated in our previous work on the thermal fatigue failure of brass die-casting dies [8]. Studies show that thermal fatigue was found to be the first damage mechanism in die-casting dies. In fact, the initial growth of the thermal fatigue cracks is facilitated by an oxidation attack on the crack surface, which forms the Cr, Si and O rich layer [8–10].

The presence of brass and oxides, in the cracks increases compressive stresses and plastic yield ($R_{p0.2}$) during the heating phase of the thermal cycle [11]. As a result, the tensile stress is further increased during the cooling phase, which in turn contributes to the continuing growth of the cracks. The thermal cracks favorite considerably the crack length while they are typically filled with a mixture of oxides [9] and residuals from the brass alloy [10]. Their structures in between the steel walls are layered or inhomogeneous and contain cracks and voids [8,9] (Fig. 2). The filling material, essentially composed of stacked layers, indicates that the filling of the cracks increases during the casting process.

The tensile stresses imposed on the die material surface layer during the cooling phase cause local failures of the filled material and promote the open thermal cracks [8].

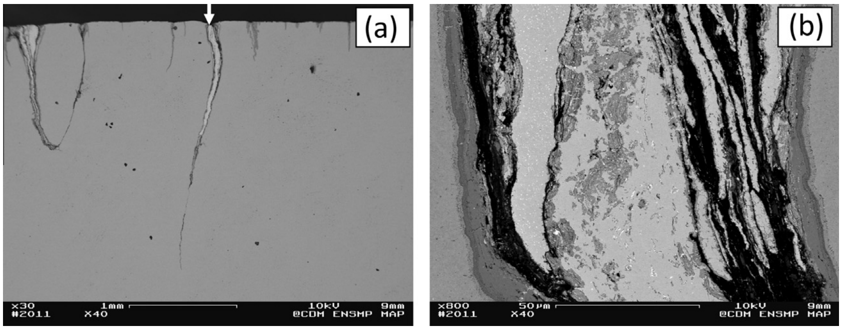

Fig. 2. Polished cross-section of a steel mold: (a) overview revealing typical thermal fatigue cracks. (b) Close-up of the crack indicated by the arrow in (a).