THE USE OF CHEVRON-NOTCH METHODOLOGY IN THE DETERMINATION OF FRACTURE TOUGHNESS OF HIGH STRENGTH TOOL STEELS

Wanderson Santana da Silva[1], Mário Boccalini Jr.[2], and Hélio Goldenstein[3*]

[1]Federal University of Santa Catarina, Blumenau, SC, BR,
[2]Instituto de Pesquisas Tecnológicas – IPT, São Paulo,Br
[3]University of São Paulo, São Paulo, SP, BR.
** Presenting Author email: hgoldens@usp.br*

Abstract

The experimental determination of fracture toughness of ultra high strength tool steels often presents limitations due to difficulty in producing fatigue pre-cracked specimens. The alternative methodology using chevron-notched samples allows reliable and reproductive results of K_{ICV}. The improvement of these steel types toughness is a permanent challenger due the high amount of large, hard and brittle carbide particles. Control of solidification, conformation process and heat treatments can change the morphology, distribution, size and type of carbides. Surprisingly cast specimens with large dendrite arm spacing and decomposed and spheroidized carbides showed higher fracture toughness.

1. Introduction

The Chevron-notched methodology is an accurate and reproductive method to measure the fracture toughness of near linear-elastic and quasi-fragile materials, as high speed tool steels, as well as cast irons, metal matrix composites, advanced ceramic and concrete. It can use short rod or bar specimens, with simple pre-cracks, assuring low cost and fast tests. The notch may be produced using abrasive discs or EDM electron discharge machining. The mechanical properties of tool steels depend on both carbide and matrix properties, and is usually characterized using hardness and flexural tests. Experimental difficulties do not encourage the wide use of fracture toughness on those steel types, so the "toughness" presented on most papers is simply the area below the curve calculated from a flexural test. The steel makers just use flexural strength because it represents, together with the hardness, a useful predictor of wear resistance. They justify this choice by the fact that the critical crack size in tool steels when heat treated for maximum hardness is very small, and the failure phenomena is almost totally defined by the nucleation process. In other words, the crack growth process has negligible influence in the fracture phenomena. Chevron notch tests has the potential to overcome this difficulty, bringing a measurement of the real fracture toughness to the discussion of mechanical and more important, wear properties. There are consolidated evidences of improvement of wear resistance of hard materials related to better toughness. As cast tool steels presents higher fracture toughness, although a lower flexural strength, as well as an extended life in some cases like rolls, in comparison whit as forged tool steels with the same hardness level. Improvement of tool performance can be attained controlling both the matrix and the type, size and distribution of hard carbide precipitates in the microstructure. For example, the as cast dendrite distribution forces a large crack path instead as forging microstructures. So the fracture toughness depends on strongly of the forging level, dendrite arm spacing size and spheroidization of carbides. On the other hand the flexural toughness may be improved by microstructure refinement. Six different high speed tool steel similar to the AISI M2 family were studied using both conventional flexural and chevron notch fracture toughness test. A conventional processed AISI M2, forged and quenched and tempered, was compared with samples from an as cast M2 steel type, submitted to high temperature carbide decomposition anneal heat treatments at 1050, 1150 and 1200ºC and quenched and tempered and finally a similar powder metallurgy high speed steel, with much finer and homogeneous carbide distribution.

2. Results

The conventional M2 steel type has higher flexural strength and lower toughness in comparison with the as cast condition. In this point has important influence de crack path.

a. In the as cast steel the toughness may be improved by more extensive decomposition and spheroidization of carbides. Annealing heat treatments using lower temperature (1050, 1100 and 1150 ºC) and shorter times (under 8 hours) did not bring significant toughness improvement, while annealing at 1200 ºC for 24 h brought strong improvement in both toughness and flexural strength.
b. Samples of a sintered powder metallurgy steel, SINTER 23, with a very fine and homogeneous carbide distribution, presented the best flexural and the worst fracture toughness results.

In a general point of view, fracture toughness and flexural strength for different steels presented contradictory behavior, i.e., large toughness was associated to small flexural strength. For the as cast steel, there are two different mechanisms improving toughness: i) in a meso scale the effect of crack deflection, which increase with increased dendrite arm spacing, as larger dendrites deflect the cracks and require increased mechanical work; ii) in a micro scale the shape, size, interconnectedness of the alloy carbides, where the spheroidization can diminish the continuity of brittle phases and mitigate crack propagation paths. This contradictory behavior can be explained by the two steps of the failure: i) nucleation; ii) crack growth. In the case of flexural strength, the system suffers the microstructure damage step before the crack nucleation, which demands large amounts of energy. The damage is facilitated by large carbide sizes and crack nucleation too. In the case of the fracture toughness, when the crack already is present at the notch, the crack growth will depend on how the material create surface energy. With a refined structure and lots of carbide matrix interfaces, the crack can grow sharply (lower surface energy – in fact lower product of surface area and specific surface energy) while with large dendritic structure and bigger carbides the crack is deflected (higher surface energy)

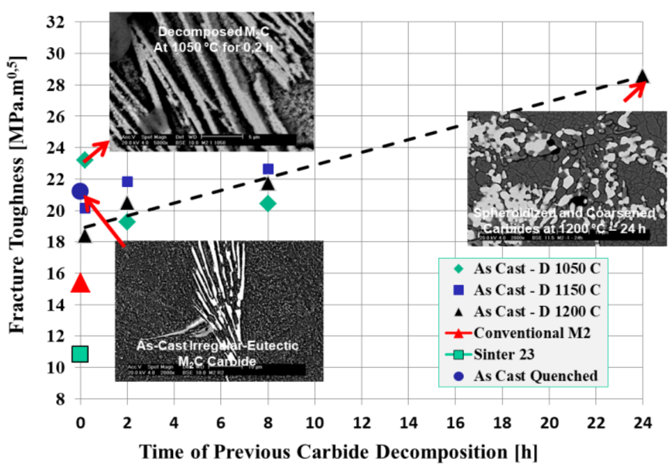

Fig.1 – Chevron notched fracture toughness of different high speed tool steel types: as cast (zero h), conventional and sintered steel, quenched and tempered, are compared with as-cast previously decomposed and spheroidized for different temperatures and times before final quench and tempering.

1. Conclusions

The mechanical characterization of HSS using just flexural strength is not sufficient. The fracture toughness of hard HSS is defined by the carbide size and distribution. The dendrite microstructure improves toughness by increasing crack path. Decomposition annealing at 1200 ^{0}C and longer than 24 h promotes notable higher values of fracture toughness of as cast HSS.

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