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AUTOMOTIVE: Advanced High-Strength and Other Specialty Sheet Steel Products for the Automotive Industry
Organized by James Fekete, Isaac Garcia, John Speer, and Matt Walp
Manufacturing with Advanced High Strength Steels II: Simulation, Springback, Joining, Tool Materials

TOOL STEEL SELECTION FOR COLD FORMING OF HIGH STRENGTH STEELS BASED ON THE STRESS DISTRIBUTION IN TOOLS

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Abstract

The excellent combination of high mechanical strength, high elongation and strain hardening of Advanced High Strength Steels (AHSS) has allowed their increasing use in the automobile industry to reduce vehicle weight and thereby fuel consumption while improving crash performance. However, the implementation of such high strength materials has generated difficulties related to wear acceleration and premature failure of forming tools. High loading during cold forming of AHSS increases to a great extent the tool requirements in terms of toughness and hardness properties. The main alternative to overcome these difficulties involves an optimized selection tool material through a proper evaluation of the stress state in the tools themselves.

In this work, stress states on tooling during cold forming of AHSS have been evaluated by means of finite element simulation. The calculated results allow selecting the most suitable tool steel in terms of microstructure and mechanical properties.

Introduction

Recently, the tool steel industry has focused several efforts in the development of high performance steel for cold working, in order to enhance the mechanical behavior of forming tools. This is particularly important in forming operations of the so-called high strength steels, where the elevated pressure applied produces an accelerated wear of the forming tools, which can lead to a catastrophic and premature failure [1].

The present scenario is drastically different to that of traditional tool steels, where wear was reduced by increasing hardness. However, such strategy cannot be applied to the forming operations of high strength steels, because the applied pressures are too high. This implies the relationship between hardness and toughness, in tool steels for cold working, must be optimized through an accurate microstructural design. This requires knowledge of the stress state acting on the tools, which can be obtained by using a finite element code. Computer simulation is widely used to define the tools needed and the type of forming operation to be employed. However, forming tools are usually considered as rigid solids and simulation focuses on the material being formed rather than on the mechanical behavior of the tools. Some behavioral results on forging tools are available [2], but there a lack of information about the mechanical requirements, which tools need during high strength steel forming operations.

Thus, the aim of this work is to obtain the stress state acting on tools used during forming operations of ultra high strength steels (AHSS), in order to determine the applicability of different tool steels.

Modeling a Forming Process by Finite Elements Model (FEM)

A FEM analysis was performed to determine the stress distribution in the tools, using the implicit formulation of the ABAQUS 6.6-1 commercial software. The study centered on forming a prototype sample (Fig. 1). The system was modeled in two dimensions supposing plane strain of the studied section.

The model was constituted of four basic components: sheet, die, blank holder and punch (Fig. 2). Commonly the component of interest is the sheet; nevertheless in this case we will centre the attention on the tools, which were considered as a deformable solid. The latter essentially adds complexity to the resolution of contacts, which increase the convergence difficulty and CPU time up considerably.

For the tools, the mesh was composed of four-node quadrilateral elements with reduced integration, and for the sheet, the elements were of complete integration, which prevents hourglassing problems during the flexion. A refined mesh was used on contact zones. The model was meshed with approximately 12500 elements.

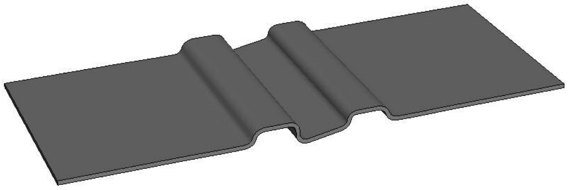


Fig. 1. Prototype sample used for FEM analysis.

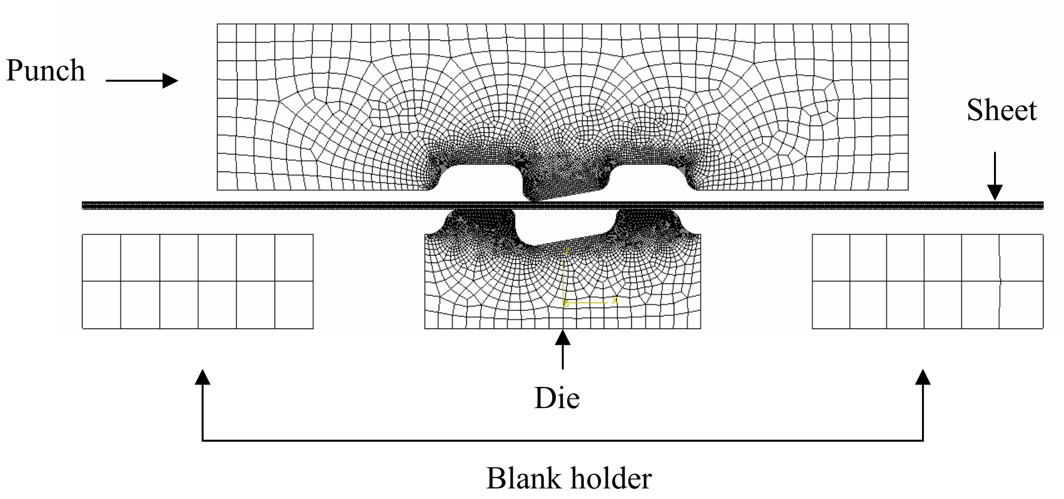


Fig. 2. FEM model of forming process.

The contour conditions were applied by controlling the displacement of the tools and the contact was assumed to be tangential with a coefficient of friction of 0.15, and in the normal direction a hard contact undernode was used to solve surface algorithms (i.e. the slave node can not penetrate in master surface).

The sheet materials were modeled in an elastic-plastic multi-linear form, by connecting values extracted from experimental traction tests performed on DIN ST-12, and AHSS TRIP 800 and DOCOL 1200 steels. Figure 3 shows a tension vs. deformation curve the three materials. The tools were modeled with a linear elastic regime with a Young modulus of 210 GPa and Poisson module of 0,3.

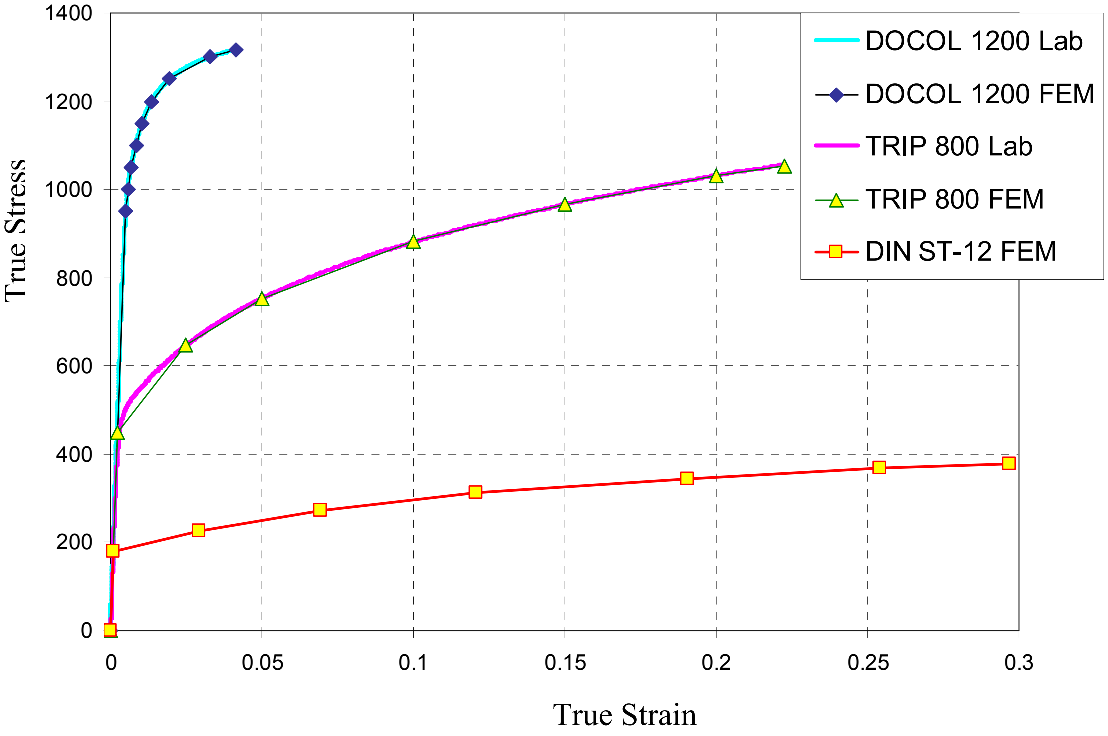


Fig. 3. True stress vs. true strain curve of the sheets modeled.

FEM Results

The simulation results were analyzed at an intermediate stage (Fig. 4b) of the forming process. It was determined that the die is the element most subjected to stress. According to the results that were extracted from a superficial path in the die as shown in Fig. 5, the von Mises equivalent tensions shown in Figs 6 and 7 depict in more detail several critical radii. It is worth noting an important stress increase when forming DOCOL 1200.

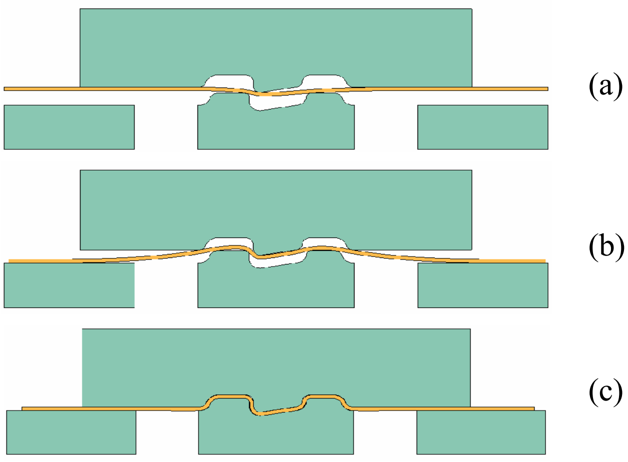


Figure 4 different stages of forming operation (a) 20%, (b) 50 %, (c) 100% total time.

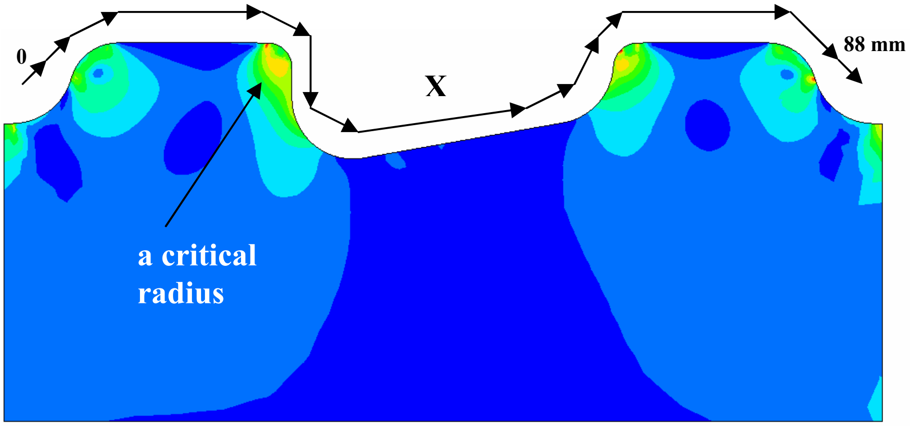


Figure 5 Superficial path used for extract the result in the die

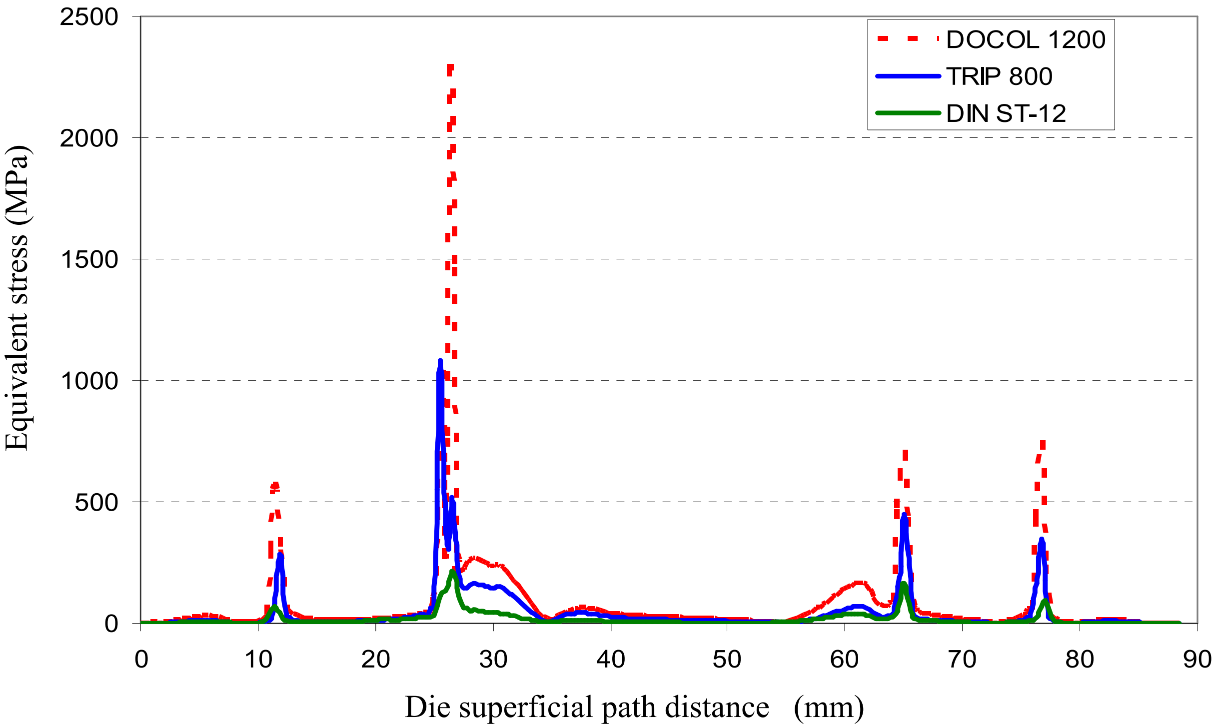


Fig. 6. Equivalent stresses at 50% into the forming process.

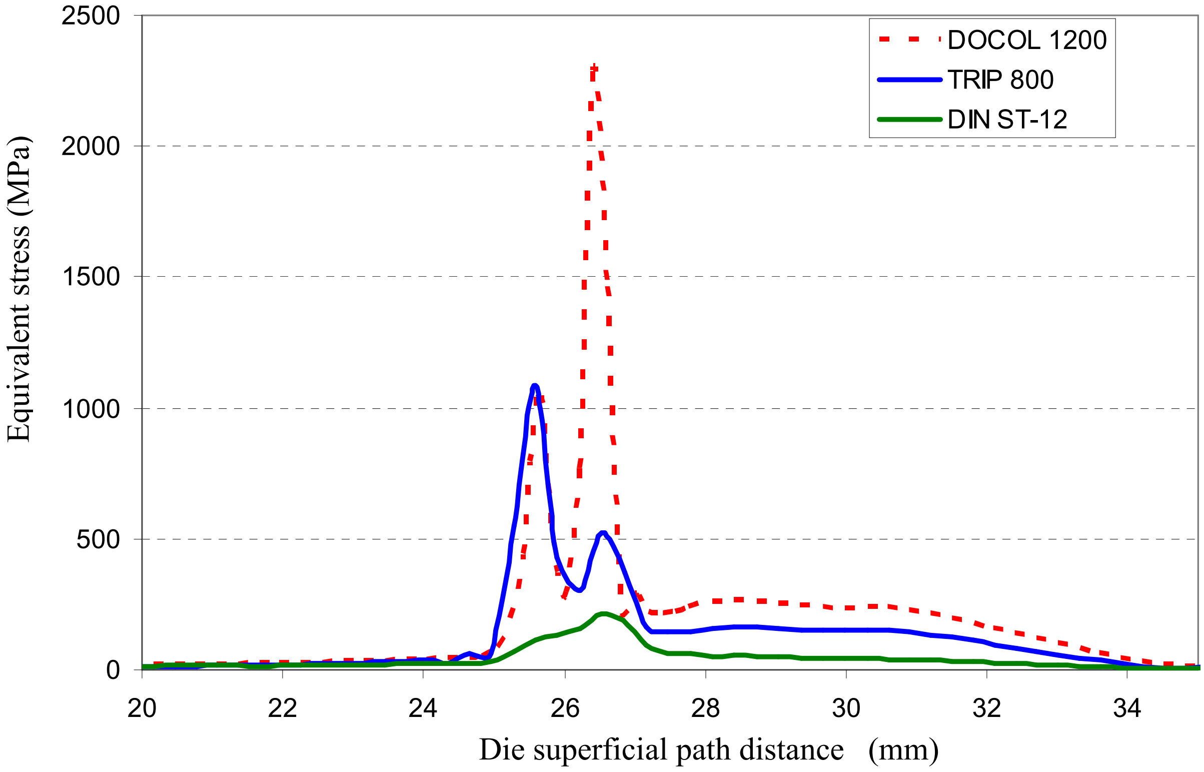


Fig. 7. A Detail of equivalent stress values on the critical radius indicated by an arrow on Fig.6.

The tension field over the most critical radius can be studied in a more detailed manner if four circumferential and concentric paths are defined as shown in Fig. 8. The radius of each consecutive circumferential path increases by 0.25 mm. The equivalent stress values of the four paths at 30%, 60% and 90% of the DOCOL 1200 forming process are shown in Figs. 9-11, respectively.

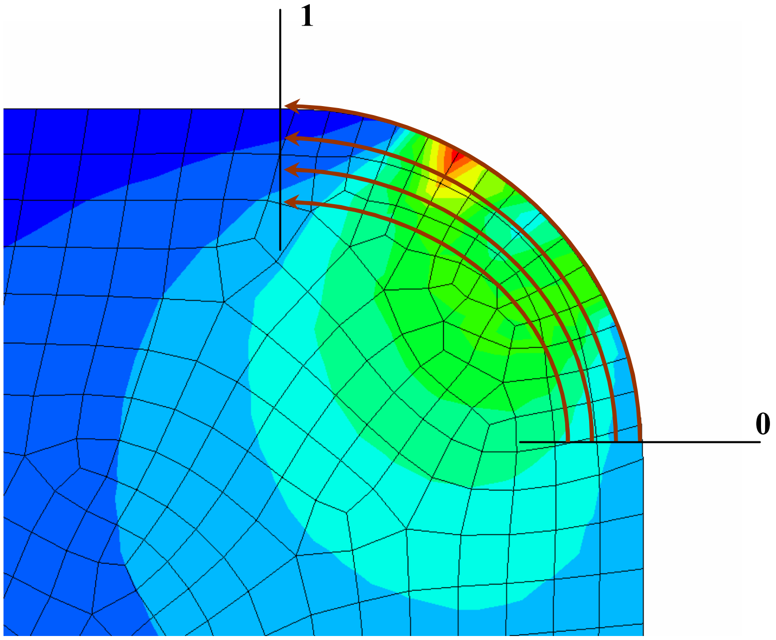


Fig. 8. Circumferential paths on the most critical radius.

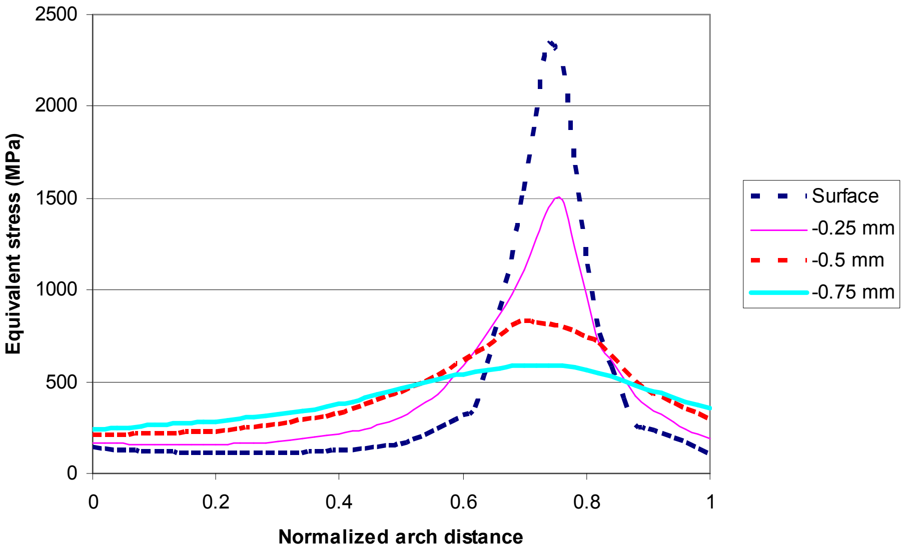


Fig. 9. Equivalent stress values in critical radius at 30% of DOCOL 1200 forming operation.

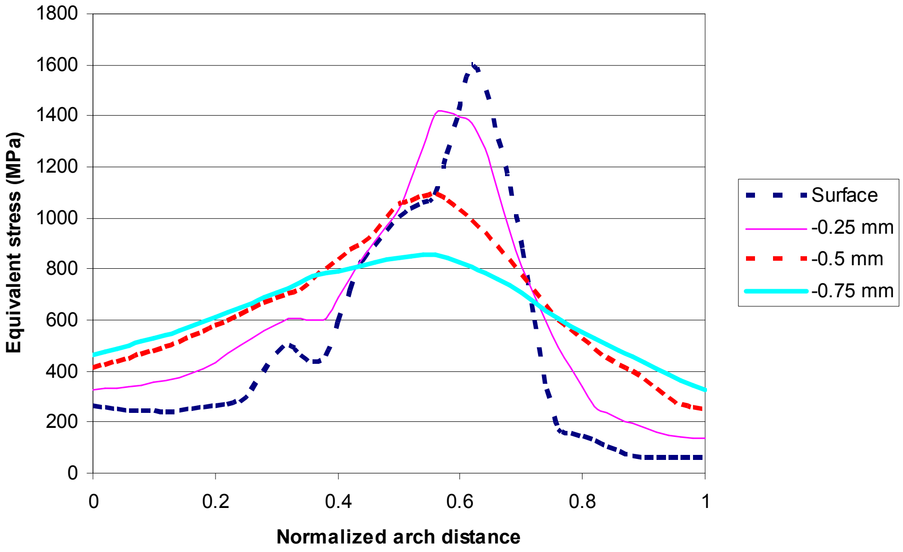


Fig. 10. Equivalent stress values in critical radius at 60% of DOCOL 1200 forming operation.

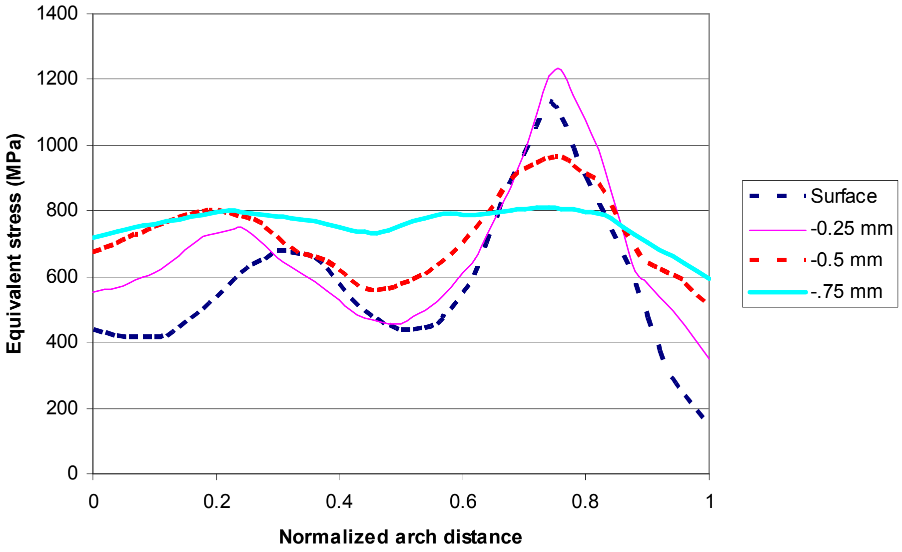
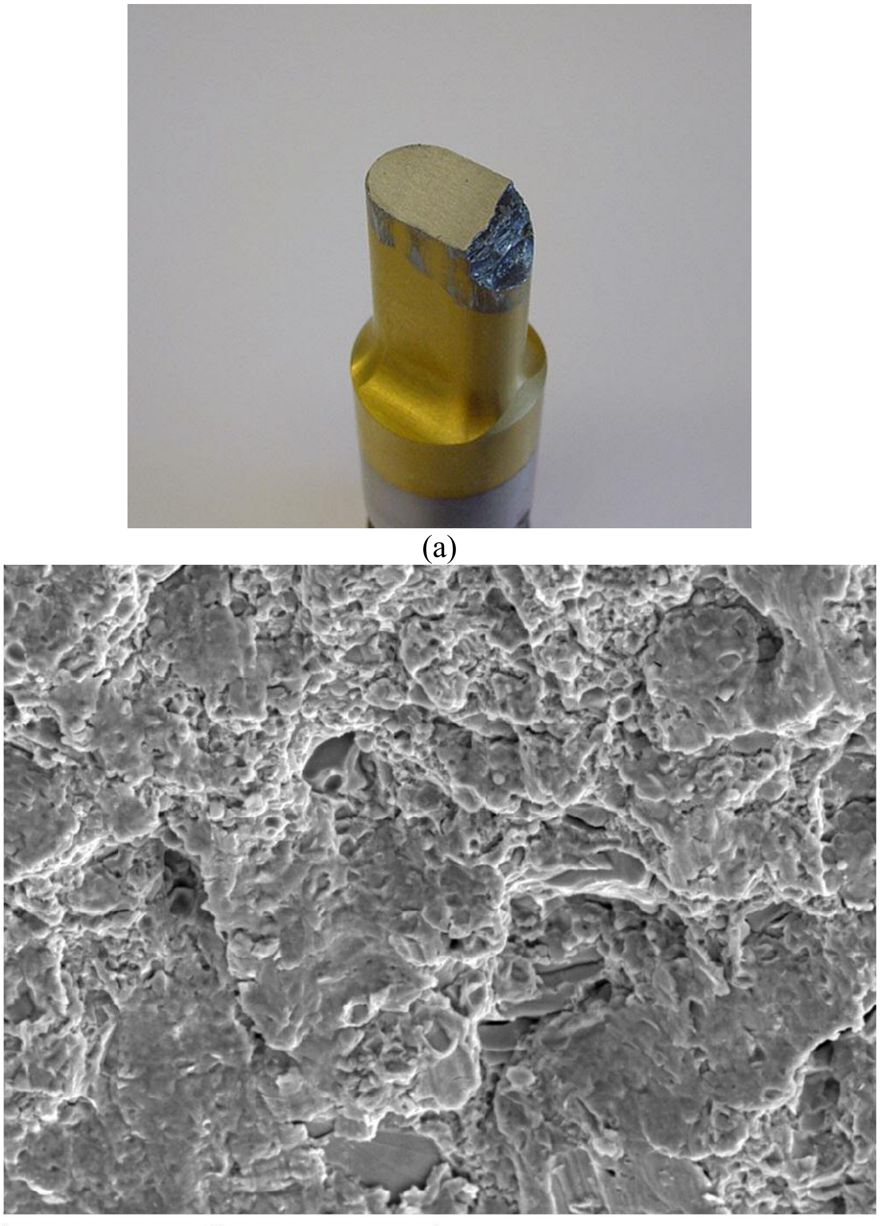


Fig. 11. Equivalent stress values in critical radius at 90% of DOCOL 1200 forming operation.

Discussion

Deep drawing of AHSS produces high stress values on tools. For TRIP800 steels stress values are close to 1000 MPa, meanwhile stress values for DOCOL1200 almost reach 2000 MPa, which is in clear contrast with the 250 MPa reached during forming of a conventional steel. When forming AHSS the tools tend to fail by wear or fatigue. Figure 12 shows a punch broken by fatigue. Fatigue acts mainly during highly demanding mechanical operations such as cutting or deep drawing. Thus the mechanical property that should be considered when testing the applicability of a tool steel is the fatigue limit. High chromium – high carbon steels, such as the

AISI D2 tool steel, are typically applied for cold forming due to their high wear resistance. However, their fatigue limit, which ranges between 600 to 900 MPa [3], make them not suitable for AHSS forming. Such recommendation has been experimentally assessed by several metal manufacturers. Powder metallurgy tool steels, which have a higher fatigue and fracture strength, are more suitable for highly demanding mechanical operations.



(a)

(b)

Fig. 12. A broken punch due to fatigue during cutting of TRIP800 is shown in (a). And (b) shows fatigue striations at the origin of failure.

The stress field in a critic zone is characterized by very high local peak of tension on contact surface, the stress level fall down in the bulk material tool, nerveless this decrease comes accompanied by a uniform stress field that includes a major zone in the sub-surface, in other words, in the surface the tension is very high in a local zone while in the bulk the high stress is more uniform around more area. This allows raise the hypothesis of the beginning of fatigue cracks take place in the subsurface, because a major probability of combine the finding a fault in material of the tool plus a high stress level.

Conclusions

In this work the stress state acting on tools during drawing of TRIP800 and DOCOL1200 steels has been characterized. Results allow an improved tool steel selection, based on their fatigue limit.

Acknowledgements

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