Hard cutting of tailored hardened 22MnB5

Till Laumann*, Ingrid Picas**, Marc Grané**, Daniel Casellas**, M. Dolores Riera**and Isaac Valls*

** Rovalma S.A., Hèrcules 49, Can Parellada, 08228 Terrassa, Spain*

*** CTM Centre Tecnològic, Av. Bases de Manresa 1, 08242 Manresa, Spain*

tlaumann@rovalma.com, ingrid.picas@ctm.com.es, marc.grane@ctm.com.es, daniel.casellas@ctm.com.es, md.riera@ctm.com.es, isaac@rovalma.com

Abstract: In the present work, the feasibility of creating low strength zones in flanges of tailored hardened 22MnB5 is evaluated by means of the combining high and low thermal conductivity tool materials. Finite Element (FE) simulations are performed in order to determine the temperature distribution in sheets when different tool materials and cooling strategies are applied. In addition, the feasibility of reducing the stress acting on tools during hard cutting of 22MnB5 steels is assessed in case of punching fully and partially hardened materials.

Keywords: cutting, tailored tool, strength, thermal conductivity

1. INTRODUCTION

In the last few years, the automotive industry has been focused on the development of an innovative sustainable vehicle design, allowing reducing CO_2 emissions and increasing the energy efficiency in all phases of vehicles life cycles. Accordingly, the application of Ultra High Strength Steels (UHSS) in structural vehicle components has enabled to satisfy the increasing demands towards vehicle safety and weight reduction.

However, cold forming of UHSS shows difficulties primarily due to the high elastic recovery of strains (springback) and the high loads acting on tools, which decrease considerably their performance. Thus, hot sheet metal stamping of 22MnB5 steel is strongly emerging as a promising technology to overcome such awkward limitations. Structural components of complex shapes and extremely high strength levels (1500 MPa) can be manufactured by combining a high work piece temperature and a rapid quenching in the die. In addition, functionally graded components can be produced by means of a good combination of high and low thermal conductivity tool materials, enabling to control sheet microstructures and mechanical properties to full-fill different requirements in a unique finished part.

Ulterior hard cutting and/or punching operations of fully hardened 22MnB5 are nevertheless, challenging processes for the automotive industry due to the high strength level of this steel. Laser cutting is often the only technique enabling to perform these operations, despite this is quite expensive and rather time consuming. In order to increase the process efficiency with economic and functional criteria, press cutting is aimed at being used due to its higher competitiveness. A smart design of the hot forming tooling may turn out to be the most feasible strategy to enable such operations. Thus, low thermal conductivity tool materials can be applied to produce low strength microstructures in flanges or areas aimed at being cut.

2. HARD CUTTING OF FULLY HARDENED 22MNB5 IN COMPARISON TO PARTIALLY HARDENED 22MNB5 MATERIAL

[Picas *et al.*, 2008] evaluated the tooling performance in hard cutting of fully hardened 22MnB5 steel. Von Mises stresses in tools were determined by means of FE simulation, and they were found to be above 2500 MPa, as shown in figure 1. Tool steels obtained by Powder Metallurgy (PM) were compared in order to assess the best strategy to overcome such a high mechanical solicitations generated in tools. A set of tools was brought up to high hardness levels (63 - 64 HRc) so that it showed good wear resistance. Another set was used at 59 - 60 HRc so that it showed higher fracture toughness. As illustrated in figure 2 a), after 5000 strokes tools with high hardness were completely fractured. Although tools with lower hardness showed a better behaviour against fracture, cutting edges became worn and rounded already at low number of cycles, as illustrated in figure 2 b).

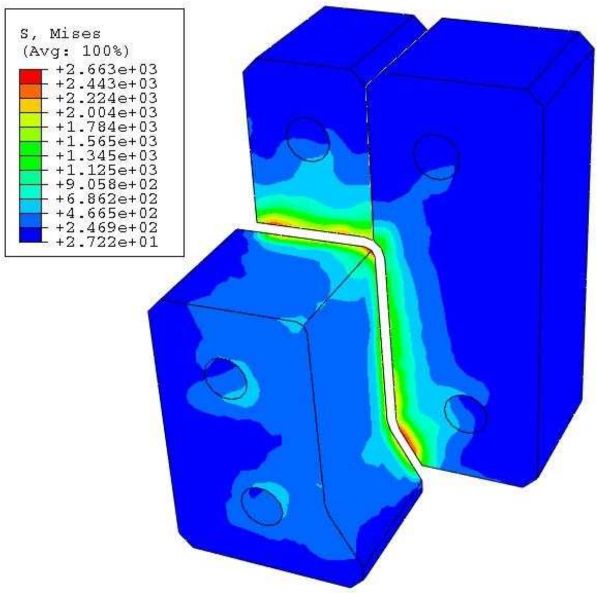

Figure 1; Maximal von Mises stresses at each node during one stroke of the cutting operation

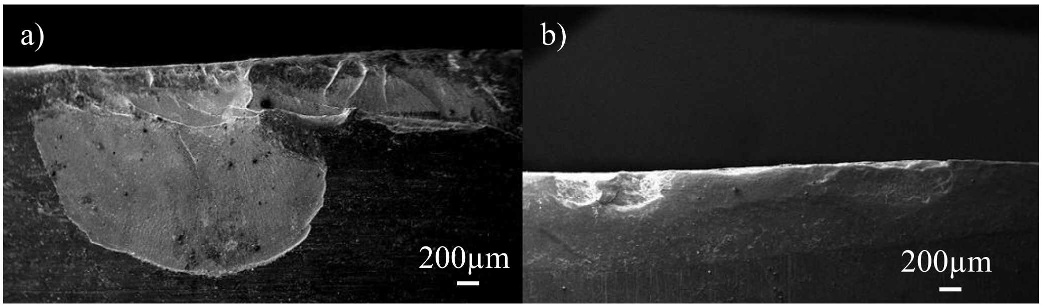

Figure 2; Damage in the cutting edge of the same punch after 5000 strokes for a) the highest hardness tools and b) the lowest hardness tools

In fact, in cold cutting fully hardened 22MnB5 material, not only tool steel selection must be optimized, but also tools must be robustly built, and cutting angles and clearances must be very well adjusted. Slight bank movements in the moment of the cut locally increase the stress on the tool due to clearance maladjustments and poor die cleanliness leads to material build-up near the cutting edge. Since nominal loads are already extremely elevated, minimal stress intensifications can lead to premature failure.

In front of these difficulties, mechanical solicitations in cutting tools can be significantly decreased by a smart combination of high and low thermal conductivity tool steels during hot stamping. In this sense, [Picas *et al*., 2009] carried out punching tests on fully and partially hardened 22MnB5 steel. Accordingly, the fully hardened material was formed during quenching under high cooling rates and showed a bainite – martensite microstructure with small presence of ferrite and a tensile strength of about 1500 MPa. The partially hardened material was obtained in flanges were low heat extraction rates were applied and as a consequence, the microstructure consisted in a lower bainitic structure with some plates of upper bainite and high content of ferrite. The tensile strength was close to the 800 MPa.

Punching tests results are shown in figure 3 for different clearances, from 5 to 21 % of the sheet thickness (1.9 mm). A 42 - 44 % reduction in punch maximal loads was obtained in the partially hardened material in comparison to the totally hardened. As a consequence, the stresses generated in the punch also decreased in such a remarkable manner, the maximal von Mises stress values went from 2900 in case of the totally hardened to 1700 MPa in the partially hardened, as illustrated in figure 4.

Thus, after these results the reduction of the mechanical solicitations acting on cutting tools seems plausible to be attained using partially hardened 22MnB5 material, showing softer microstructures formed through the application of low heat extraction rates during the hot stamping process.

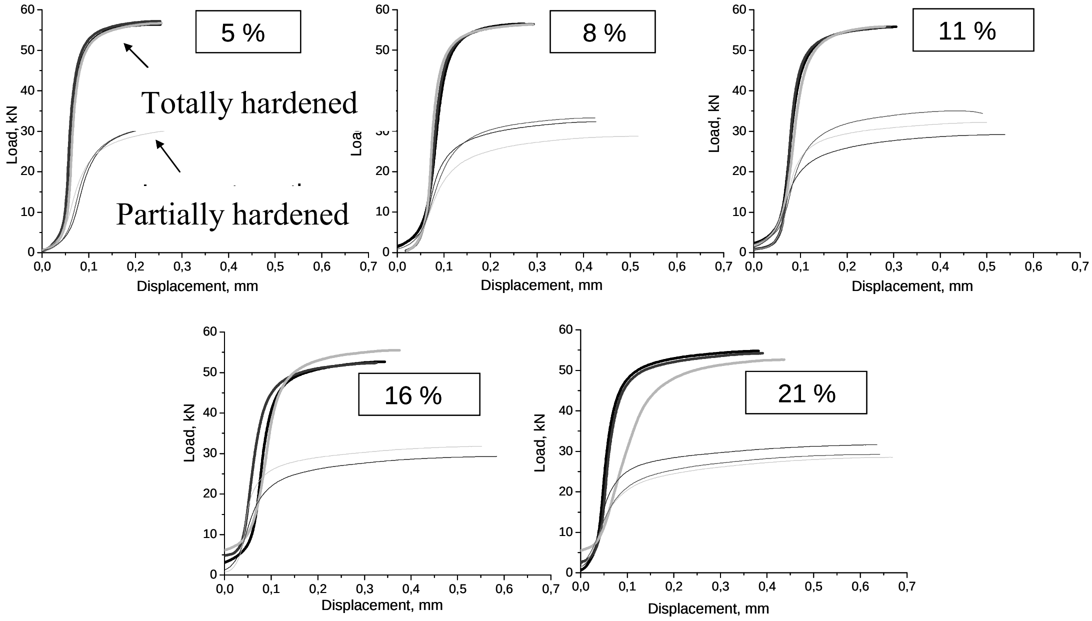

Figure 3; Load – displacement diagrams of punching tests

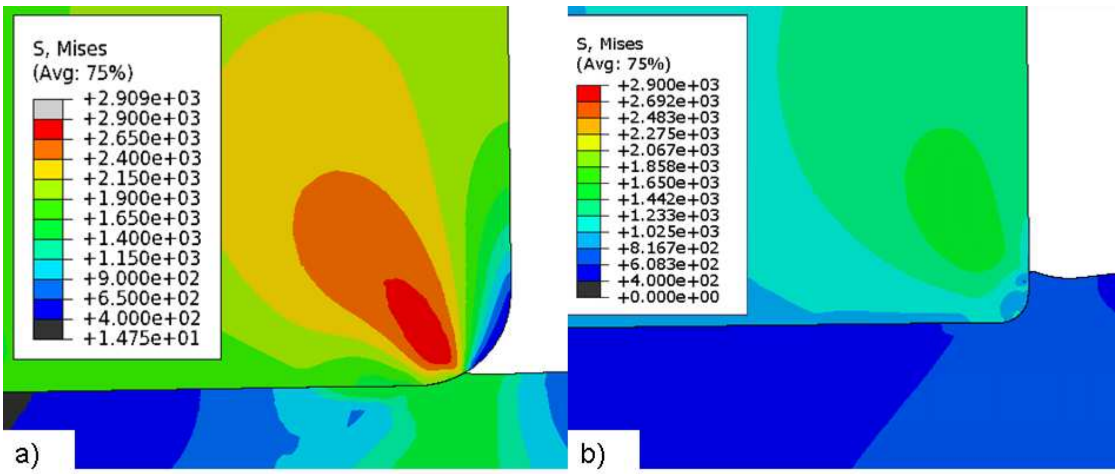

Figure 4; Von Mises stress distribution in the punch. a) Totally hardened 22MnB5 and b) partially hardened 22MnB5

3. PRODUCTION OF 22MNB5 SHEETS WITH GRADED MECHANICAL PROPERTIES BY MEANS OF DIFFERENT HEAT EXTRACTIONS

The mechanical properties of the 22MnB5 hot formable material can be altered and adapted to the specific demands of each component by different approaches. As the microstructure and the resulting properties are strongly correlated to the heat treatment, the mechanical properties in a component can for instance be altered by locally different extraction rates during quenching or different annealing or subsequent tempering strategies.

Within this work a strategy is proposed to functionally adapt the mechanical properties of the desired part by quenching the austenized 22MnB5 steel in a tool consisting of zones having different thermal conductivities and thus different heat extraction rates. Therefore various materials were developed providing thermal conductivities in the range of 5 up to 70 W/mK, while common tool steel grades show thermal conductivities in a comparatively small range of just 24 up to 29 W/mK. Assuming a sufficient contact pressure between the sheet and the tool during the quenching process the microstructure and thus the mechanical properties can be altered according to the thermal conductivities applied in desired zones of the components. Generally high extraction rates in zones of high thermal conductivity result in a hard and martensitic microstructure, whereas low extraction rates in zones of reduced thermal conductivity result in softer ferritic and bainitic microstructures. Assuming a sufficient pressure and good contact between the tool and the sheet to be formed the cooling rate is mainly given by the thermal conductivity of the tool steel and the cooling system. The combination of materials with different thermal conductivities allows producing components with graded mechanical properties and a sharp transition zone. This approach involves no additional process steps like selective annealing or tempering and is thus very promising concerning functional and economical aspects.

To evaluate the influence of different thermal conductivities on the temperature distribution, simulations of tools built of three different segments were performed, see figure 5. All tool set-ups have the objective to produce components with soft flanges to ease subsequent steps like hard cutting for instance, a maximum strength in the middle part and a preferably small transition zone of the mechanical properties. While the central part is equipped with a water cooling system to guarantee maximum extraction rates and high strength levels, the outer segments have a low thermal conductivity to retard the cooling of the sheet and enable reduced strength levels. The properties of the cooling system are the same for each configuration. Beside the widely-used DIN 1.2367 tool steel with a thermal conductivity of approximately 27 W/mK different high and low thermal conductivity materials from Rovalma were investigated within the simulations. The HTCS 130WU has a thermal conductivity of 57 W/mK, the GTCS550 11 W/mK and the GTCS550-K160, see figure 5.

The application of high thermal conductivity steel grades in the central part has different advantages in comparison to the DIN 1.2367. The total cycle time which is necessary to cool down the part below the martensitic start temperature with a sufficient high cooling rate - in order to achieve a fully martensitic structure - can be reduced from 22 seconds to 11 seconds. Another benefit of the high thermal conductivity and thus of the reduced cycle time is a sharp transition zone between the segments and a higher temperature in the flange areas, which is essential for producing zones with a reduced strength level. Comparing case a) and b) of figure 5, this means tool set-ups with GTCS550 in the outer segments for both cases, a big difference of the surface temperature, 320°C (case a)) compared to 460°C (case b)), is visible due to the reduced cycle time in case that HTCS 130WU is used for the central segment.

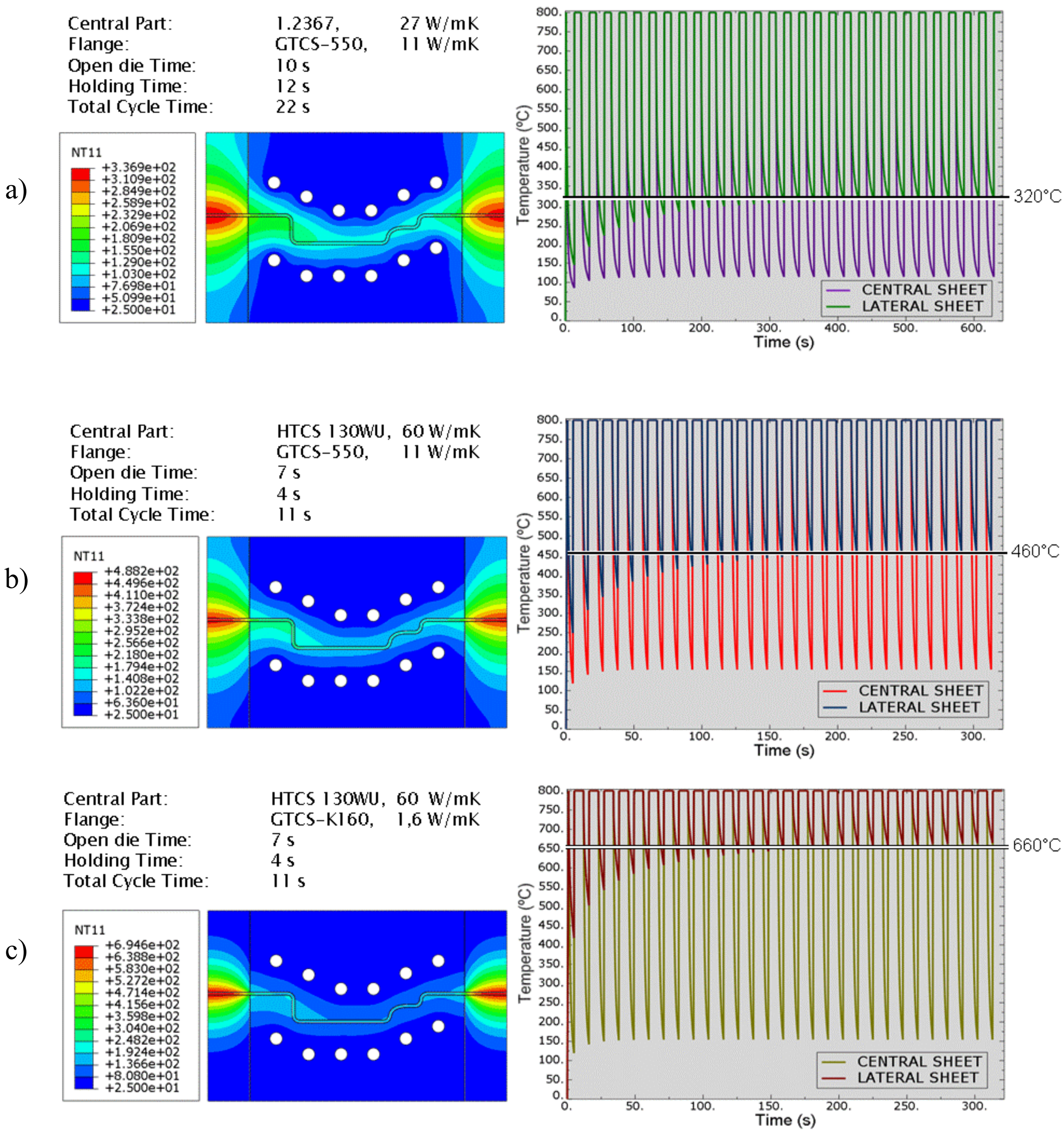

Figure 5; Temperature distribution and evolution of different tool set-ups:
a) 1.2367 + GTCS55
b) HTCS 130 WU + GTCS550
c) HTCS 130WU + GTCS-K160

Try-out tests were performed to evaluate the mechanical properties of the 22MnB5 being quenched with the parameters following the results of the simulations. In each case stripes of the austenized 22MnB5 were quenched between two blocks of GTCS-550 and GTCS-K160 respectively, which were preheated to the required surface temperature. The parameters for each set-up and the results of the tensile tests are displayed in table 1.

	Flange material:	flange temperature [°C]	holding time [s]	$R_{p0,2}$ [MPa]	R_m [MPa]	A25 [%]
a)	GTCS-550	320	12	970	1177	10,48
b)	GTCS-550	460	4	579	719	-
c)	GTCS-K160	660	4	391	635	21,4

Table 1; Mechanical properties of the 22MnB5 after being cooled down from austenizing temperature depending on the different set-ups

As expected a significant loss of strength and an increase of elongation can be detected in direction of higher surface temperatures and reduced holding times. Further on the comparison of case a) and b) reveals that the use of low thermal conductivity material is especially advantageous in combination with high thermal conductivity material, as the total cycle time can be reduced and thus the surface temperature in the flange areas be increased. Comparing a holding time of four respectively twelve seconds and usage of GTCS-K550 material in both cases, a difference in ultimate tensile strength of 458 MPa can be detected, see table 1.

4. CONCLUSION

The use of segments with different thermal conductivities combined in one tool allows producing tailored hardened 22MnB5 components with a wide range of properties. In comparison to the fully martensitic microstructure a reduction of the strength levels well below 50% is possible even if the holding time is only four seconds. The combination of low thermal conductivity materials for zones of reduced strength levels and high thermal conductivity materials for zones of maximum resistance is very advantageous, as a holding time of four seconds is sufficient to achieve the desired mechanical properties in the component. Further on the simulations display a sharp transition between zones of high and low thermal conductivity.

Zones of reduced strength are advantageous for a number of applications as well as for subsequent processing steps like hard cutting for instance. Hard cutting of fully martensitic and 1.9 mm thick 22MnB5 is adherent to stress levels of more than 2500 MPa. To some extent it is possible to tackle the high loads and to avoid premature failure of the tool by employing specially designed tool materials. Further more the cutting loads can significantly be reduced if the strength of the respective zones in the blank can be decreased. Experimental punching tests as well as simulations display a markedly decline of punch loads and stresses in the soft zones of the sheet.

REFERENCES

[Picas et al., 2008] Picas, I.; Hernández, R.; Casellas, D.; Casas, B.; Valls, I.; "Tool performance in cutting hot stamped steels"; In: *Proc of the Hot Sheet Metal Forming of High-Performance Steel*, pp.179-189; Kassel 2008; ISBN 978-3-937057-18-7

[Picas et al., 2009] Picas, I.; Hernández, R.; Casellas, D.; Valls, I.; "Cold cutting of microstructurally tailored hot formed components"; In: *Proc of the Hot Sheet Metal Forming of High-Performance Steel*, pp.115-126; Luleå 2009; ISBN 978-3-937524-84-9