Materials Research Proceedings 28 (2023) 755-760 https://doi.org/10.21741/9781644902479-82

Heat assisted V-bending characteristics of high strength S700MC steel

GÖRTAN Mehmet Okan[1,a *], CAGIRANKAYA Fatih[2,b] and OZSOY Oguz[2,c]

[1]Hacettepe University, Mechanical Engineering Department, Ankara, Turkey

[2]TEKNOROT Steering & Suspension Parts, Düzce, Turkey

[a]okangortan@hacettepe.edu.tr, [b]fatih.cagirankaya@teknorot.com, [c]oguz.ozsoy@teknorot.com

Keywords: V-Bending, Springback, Mild Temperature Forming, High Strength Steel

Abstract. Increasingly stringent regulations force automotive manufacturers to reduce their product weights without compromising passenger safety. To overcome this problem, high strength steels are used that enable a higher payload capacity whilst reducing the plate thickness and overall weight. However, high strength steels are generally associated with lower formability and significantly greater springback compared to mild steels. In the current study, bendability characteristics of high strength S700MC steel in mild temperatures are investigated using V-bending tests. A temperature range between 25°C and 650°C is analysed. Springback characteristics as well as hardness distribution along the thickness direction in the bent area is investigated for several bent samples.

Introduction

Due to the stricter demands in terms of greenhouse gas emission regulations, automotive manufacturers are forced to use lightweight solutions in their design. Two major approaches have been developed in sheet metal forming industry to reduce the thickness and hence weight of parts without compromising the safety and toughness [1]. The first one is to replace conventional materials with their higher strength counterparts and so to be able to carry the same loads using less material. However, due to the limitations in ductility of advanced high strength steels (AHSS) and ultra-high strength steels (UHSS), this strategy can be only used in comparatively simple geometries such as bumper reinforcements, door beams or seat tracks, which can be cold-formed using multiple stage bending or roll-forming processes. The second strategy is the application of a press hardening process where austenitized steels are hot-formed in a press and quenched in the same die system. That way, martensitic microstructure is obtained, resulting in strengths that exceed 1500 MPa in the produced parts without major formability problems [2]. Nevertheless, press hardening process is significantly more energy demanding than conventional stamping or deep drawing processes. In best-case scenario, more than 69% of the energy related to forming is consumed during the heating and related operations in press hardening [3].

There are multiple studies about formability and especially about bendability of steels. Recent ones focus on advanced high strength steels. Majority of the articles investigate critical bending angle and fracture formation depending on the used steels microstructure and mechanical properties. Four different failure types are defined for bending of steels, namely waviness with a flattening on the outside, ductile cuts, fine cracks and instable cracks [4]. Furthermore, it is reported that fracture formation starts during bending before reaching the maximum force in the process [5]. Moreover, regardless of microstructure, bendability of steels improves as strain hardening increases and resistance against crack formation getting higher [6-8]. However, all these studies are conducted at room temperature.

To increase the energy efficiency of the forming operations and to be able to use high strength steels in the manufacturing of complex parts, it is intended to develop mild temperature forming strategies for conventional high strength steels. The idea behind the mild temperature forming is to shape steels at a temperature level below austenitizing region. That way a decrease in strength and increase in formability is expected. Hence, springback can be reduced. Moreover, since the temperatures are kept below austenitizing region, minimum change is foreseen in microstructure and mechanical properties after forming process is finished and parts are cooled to room temperature. In the current study, bending characteristics of high strength steel S700MC is investigated at mild temperatures ranging from 25°C to 650°C. Springback after bending is evaluated. Moreover, mechanical properties are characterized using hardness measurements.

Material and Methodology

A hot-rolled structural high-strength steel sheet S700MC made for cold forming with a thickness of 4 mm has been used in the study. Mechanical properties and chemical composition of the material are given in Table 1 and Table 2, respectively.

Table 1. Mechanical properties of S700MC steel.

Yield Strength	Tensile Strength	Elongation
792.2 MPa	941.2 MPa	13.2%

Table 2. Chemical composition of S700MC steel (in mass %).

C	Si	Mn	Ni	Mo	Fe
0.78	0.083	1.94	0.15	0.168	balance

Bending samples are prepared using shear-cutting with a length and width of 150 mm and 50 mm, respectively. Width of the samples coincides with the rolling direction of the steel sheets. V-bending test are conducted on those samples according to the ISO 7438:2020 standard. A bending die with an angle of 90° is prepared for this purpose. Since mild steels are usually bent with a r/t ratio of 1, the same ratio is used in the experiments. Die system is shown in Fig. 1.

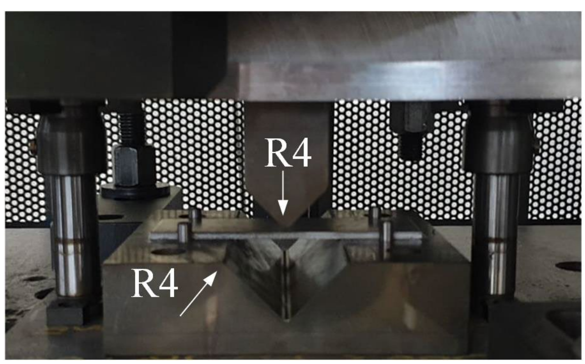

Fig. 1. V-bending die system.

Bending tests are conducted at room temperature and additionally at elevated temperatures ranging from 150°C to 650°C with increments of 100°C. Induction heating is used to heat the samples in bending region. Temperature of the samples are measured with a laser sensor during heating. A hydraulic press with a capacity of 400 tons is used for forming tests. Motion control mode is used and ram speed is set constant to 40 mm /sec. Dwell time at lower dead center is set to 2 seconds. All samples are cleaned with acetone prior to bending. No lubrication is used.

All bending tests are repeated at least three times. Springback on all samples are measured using mechanical angle gauge with a precision of 0.1°. Crack formation on outer side of the bent samples are investigated with optical microscopy and dye-penetrant testing.

All bent samples are cut in the middle section. The cross section is ground with sand papers between P400 and P2500 grit. Afterwards, surfaces are polished with 6 µm and 1 µm diamond solution. Prepared surfaces are etched with 4% Nital solution for approximately 10 seconds. Microstructure of the bent section is investigated using optical microscopy (Nikon Eclipse LV150).

Strain hardening behavior of the samples in the bending region along the thickness direction is characterized using Vickers hardness measurements according to ISO 6507-1 with a load of 500 g and dwell time of 15 seconds (Future-Tech FM-700e).

Results and Discussion

Outside section of samples bent at different temperatures are shown in Fig. 2. A clear crack formation is observed on samples formed at temperatures below 550°C. There are multiple reasons for the crack formation. At room temperature, ductility of the material is not sufficient to accomplish the bending. However, when the temperature is increased, material enters the blue brittleness region. Therefore, it becomes highly brittle and blue cracks are observed. Apparently, the investigated material exits the blue brittleness region at 550°C and crack free samples are generated at temperatures above that level.

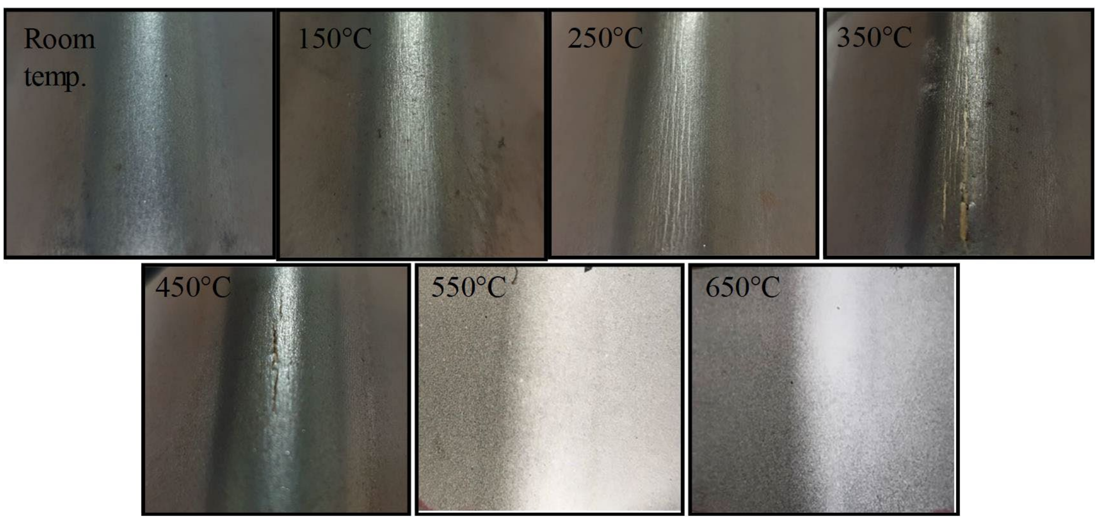

Fig. 2. Outside section of the bent samples at different temperatures.

Side view of the bent samples are shown in Fig. 3. Thanks to the low r/t ratio, springback value of sample bent at room temperature is comparatively low at 90.6°. At temperatures higher than 150°C, no springback is observed in the bent samples. In the die-design process, every bending angle above 90° is a challenge. Even though springback at room temperature of the investigated case is low, it necessitates a certain over-bending. Since there is no springback at elevated temperatures, it is seen as major advantage of mild temperature forming of S700MC steel.

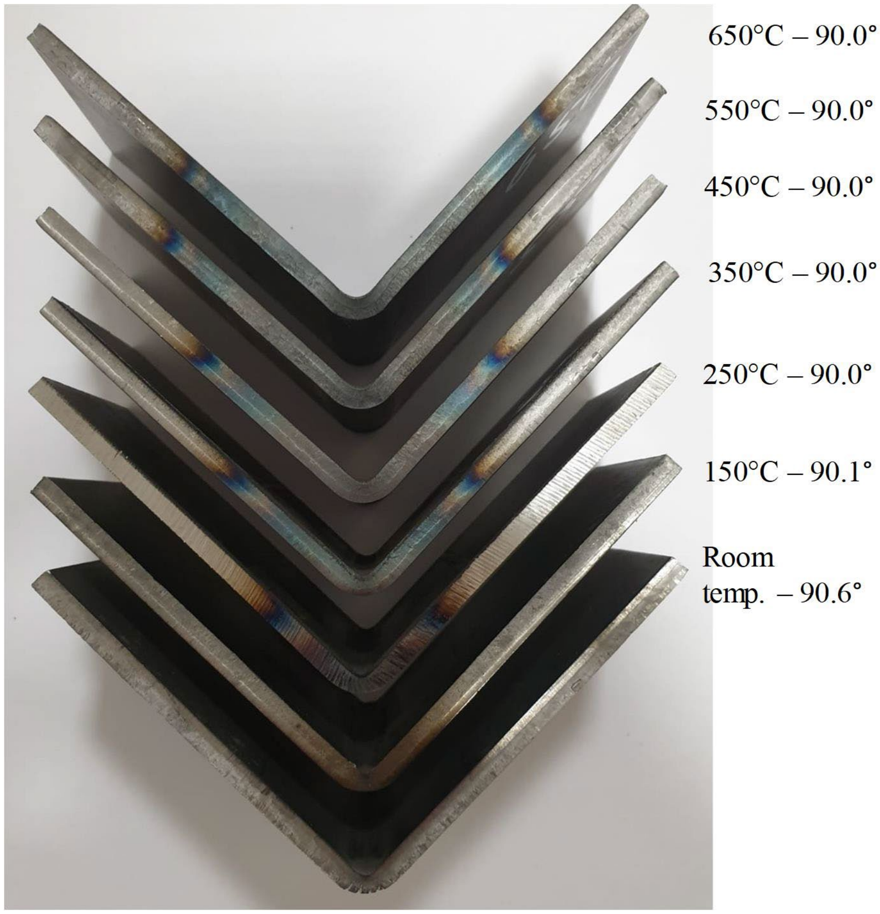

Fig. 3. Side view of bent samples at different temperatures.

Optical microscopy results are shown in Fig. 4. Initial microstructure of S700MC steel is predominantly in ferritic-pearlitic form. This structure remains the same after bending at all temperatures. Since all investigated temperatures were below A_1 level, austenitizing of the microstructure was not expected. Moreover, there isn't any significant change in the grain size. This is attributed to the fast heating and cooling of the material prior and after bending. During heating of steels below A_1 temperature, recovery and recrystallization is expected which yields in dislocation density drop and grain growth. However, both of those processes are time dependent. Thanks to rapid heating and cooling, recrystallization wasn't observed in the microstructure.

Optical microscopy investigations also reveal that there are buckling marks on the inside of samples bent at room temperature. Those marks may act as stress concentration points in repeated loading conditions and reduce fatigue life significantly. However, no sign of buckling is observed at samples bent at 550°C and 650°C. It is seen as an important advantage of forming at mild temperature for S700MC steel.

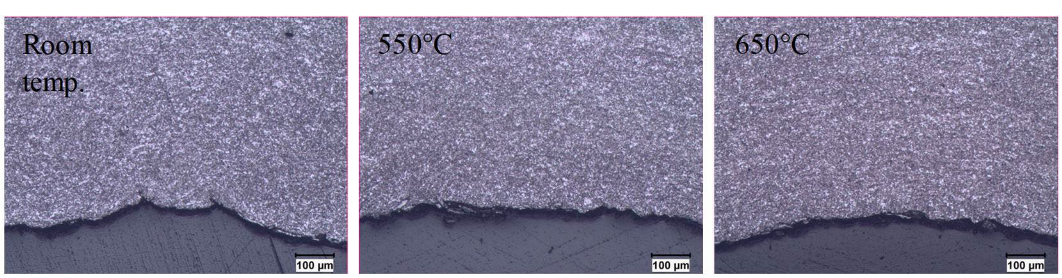

Fig. 4. Microstructure of bent samples.

An important aspect of mild temperature bending of high strength steels is the mechanical properties after forming. Steels formed at room temperature are expected to exhibit a certain amount of strain hardening. As a result, static strength of the parts increases. Strength change can be characterized using hardness measurements [9]. In the current study, Vickers hardness of bent samples along thickness direction in bent are is measured. Results are shown in Fig. 5.

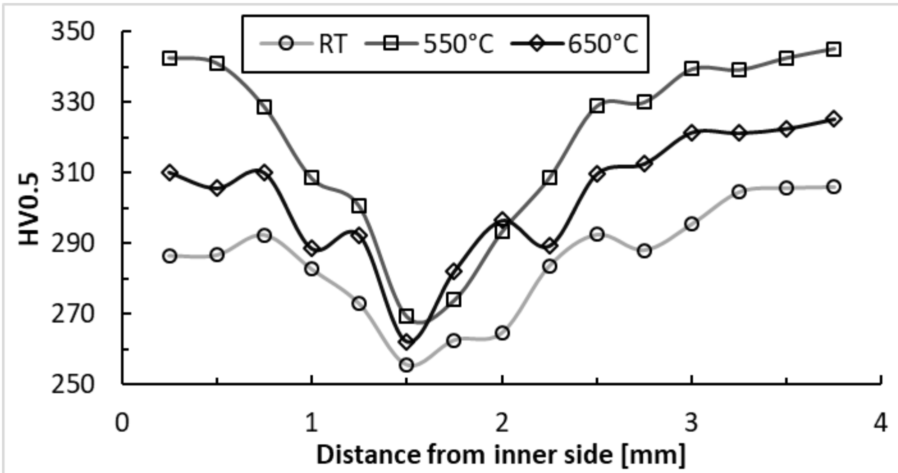

Fig. 5. Hardness distribution along thickness direction.

It is clear from Fig. 5 that the neutral axis of all investigated samples are shifted about 0.5 mm inwards. As we move away from the neutral axis both inwards and outwards, strength of the investigated steel increases due to strain hardening. Since strain value on the outside is higher due to neutral axis shift, hardness level on the outside is approximately 7% higher compared to inside section. When the bending temperature is increased to 550°C, a more significant strain hardening is observed in the bent area. Usually, if temperature of steels is increased, first recovery and later recrystallization is expected. As a result, decline in dislocation density and grain growth occurs. Therefore, strength of steels decrease. However, in the investigated case, a more significant strength increase is observed in samples bent at 550°C compared to the ones bent at room temperature. Underlying reason for that increase should be investigated more in detail using microstructural analysis.

When hardness distribution of the sample bent at 650°C is compared to the one bent at 550°C, a drop in hardness is observed which is less than 10%. All these investigations suggest a strain hardening in the investigated steel even at elevated temperatures.

Summary

In the current study, bending characteristics of hot-rolled structural high-strength steel sheet S700MC made for cold forming is investigated at mild temperatures. Studied temperatures are kept below austenitizing temperature to decrease the energy requirement of the bending operation while increasing the formability characteristics. Following conclusions are drawn:

- Increase in temperature enables better formability and reduced crack formation risk for S700MC steel.
- Crack formation on the outside of the samples formed at temperatures up to 450°C is observed which is due to the blue brittleness of the material in that region
- Reduced springback is observed as the bending temperature increases.
- A significant hardness increase is observed in the samples bent at 550°C and 650°C compared to the ones bent at room temperature.

- In the outer and inner region of all bent samples, an increase in hardness is observed which indicates a strain hardening despite the rise in temperatures.
- No grain growth is observed in the samples bent at elevated temperatures.

Acknowledgements
The conducted work was under a project funded under the SMART EUREKA CLUSTER on Advanced Manufacturing Program. Moreover, the authors thank the Turkish Research Council for financially supporting the project 9210025.

References
[1] S. Keeler, M. Kimchi, P.J. Mooney (Eds.), Advanced High-Strength Steels Application Guidelines Version 6.0, 2017.
[2] H. Karbasian, A.E. Tekkaya, A review on hot stamping, J. Mater. Process. Technol. 210 (2010) 2103-2118. https://doi.org/10.1016/j.jmatprotec.2010.07.019
[3] E. Meza-Garcia, A. Rautenstrauch, M. Braunig, V. Krausel, D. Landgrebe, Energetic evaluation of press hardening processes, Proc. Manuf. 33 (2019) 367-374. https://doi.org/10.1016/j.promfg.2019.04.045
[4] M. Kaupper, M. Merklein, Bendability of advanced high strength steels—A new evaluation procedure, CIRP Ann. - Manuf. Technol. 62 (2013) 247-250. http://doi.org/10.1016/j.cirp.2013.03.049
[5] A. Mishra, S. Thuillier, Investigation of the rupture in tension and bending of DP980 steel sheet, Int. J. Mech. Sci. 84 (2014) 171-181. http://doi.org/10.1016/j.ijmecsci.2014.04.023
[6] C. Suppan, T. Hebesberger, A. Pichler, J. Rehrl, A. Kolednik, On the microstructure control of the bendability of advanced high strength steels, Mater. Sci. Eng. A 735 (2018) 89-98. https://doi.org/10.1016/j.msea.2018.07.080
[7] D. Rèchea, T. Sturel, O. Bouaziz, A. Col, A.F. Gourgues-Lorenzon, Damage development in low alloy TRIP-aided steels during air-bending, Mater. Sci. Eng. A 528 (2011) 5241-5250. https://doi.org/10.1016/j.msea.2011.03.042
[8] K. Benedyk, A. Pichler, T. Kurz, O. Kolednik, Die Versagensmechanismen pressgehärteter und hochfester Stähle im Dreipunkt-Biegeversuch, BHM 159 (2014) 122-129. https://doi.org/10.1007/s00501-014-0237-1
[9] M.D. Taylor, K.S. Choi, X. Sun, D.K. Matlock, C.E. Packard, L. Xu, F. Barlat, Correlations between nanoindentation hardness and macroscopic mechanical properties in DP980 steels, Mater. Sci. Eng. A 597 (2014) 431-439. http://doi.org/10.1016/j.msea.2013.12.084