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HOT-FORMING PROCESS TO IMPROVE PRODUCT STRENGTH & REDUCE VEHICLE WEIGHT

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***Abstract*- Hot-Forming process to improve product Strength & Reduce Vehicle Weight up to 30% to 50% as compared to conventional cold forming grades. Hot stamped components with full marten site exhibit high tensile strength and hardness, but the poor ductility restricts their application on some components, such as A pillar, B pillar, which needs multi strength in different regions. It is important to partly achieve softer structure with more ductility, to increase the crashworthiness and sudden impact absorption of the whole component and such that improving the safety performance. This work define the hot forming of high strength steel with tailored properties by applying different die temperatures and annealing processes.**

Keywords: **vehicle weight, temperature.**

I. INTRODUCTION

Due to high demand for reduced vehicle weight, improved safety and crashworthiness qualities, increasing hot forming parts are used for automobile structural components from ultra-high strength steel. From Last few years use of hot stamping parts in automotive industry is suddenly increased instead of cold forming parts. By using heated blanks which forms and hardens quickly in the die, parts can be made larger, stronger and more complex than ever before. And maybe it will eliminate some of the issues that exist during the cold stamping and forming of advanced high strength work materials that can lead to spring back and cracking. But due to this hot process, high demands placed on the tool steel during hot stamping increases risk of tool failures, leading to production stops and delays. We found some different type grades and coatings that are appropriate for the varied production issues on the inserts in hot stamping. The general process of hot stamping technology is listed as follows:

Forming high performance blanks in high temperature (over 950) and quenching in-die, thereby obtaining homogeneous marten site and high strength martensitic parts. The full martensitic parts have characteristic of very high strength (1500 MPa - 1700 MPa) and poor ductility generally less than 5%. Thus, generally high strength steel hot stamped parts are not suitable for the impact absorbing parts of automobiles .Except for increasing structural strength of vehicle, the problem of matching mechanical properties of parts & body security has been of concern. However, with the more widespread application of ultra-high-strength steel, the ability of mechanical properties and safety performance of automobile parts has been proposed that different mechanical & chemical properties are needed in different regions of the same parts, namely tailored properties. Generally speaking, there are some ways to achieve tailored properties: tailor welded blanks; poor slab; different initial temperature of the heated blank, hot-forming die material of different thermal conductivity, different die temperature; different contact area and subsequent heat treatment i.e. tempering and annealing etc. By means of die slotting locally, successfully made the high strength of the contact area with the forming die and the low strength of the regions without contact. With the employment of tailor welded blanks, obtained the automotive B pillar which can meet the crashworthiness requirements of roof and side, with a reduced part mass by 30% to 50%.

Varied the heat transfer coefficient from 7 to 66 W/mK, using some special equipment which has controlled the heat transfer of the heated blank effectively. The present paper applied following methods to get tailored properties, namely dividing die into two zones, annealing and hardening of part.

In the research a laboratory-scale hot-formed A & B-pillar is produced using a segmented die with local heating and cooling zones such that the cooling rate of the heated blank was controlled locally during the hot forming process. The experiments with a plate tool which show a heated and a cooled zone According to the tailored tempering process. Controlled the cooling rate of the austenitized heated blank by local heating of the die and consequently adjusting microstructure evolution and resulting required mechanical properties. Annealing the hardened part has been researched to obtain tailored properties .This study focused on the contrast of the two methods to fulfil tailored properties.

II. EXPERIMENTAL PROCEDURE

A. Types material and parameters-

In this paper, the studied high strength steel belongs to boron steel specialized for hot forming process, named BTR165. The thickness is 1.85mm and the composition is given in Table .

The following composition is provided by the material supplier.

TABLE I. CHEMICAL COMPOSITION OF BTR165 & MATERIAL BEHAVIOR

Steel.	**Al**	***B***	***C***	***Cr***	***Mn***
20MnB5	0.04	0.001	0.16	0.22	1.05
BTR165	0.03	0.002	0.23	0.16	1.18
8MnCrB3	0.05	0.002	0.7	0.37	0.75
27MnCrB5	0.03	0.002	0.25	0.34	1.24
37MnB4	0.031	0.001	0.33	0.19	0.81

Steel.	***N***	***Ni***	***Si***	***Ti***
20MnB5	--	0.01	0.40	0.034
BTR165	0.005	0.12	0.22	0.040
8MnCrB3	0.006	0.01	0.21	0.048
27MnCrB5	0.004	0.01	0.21	0.041
37MnB4	0.006	0.02	0.31	0.046

Steel	***Martensite start temperature in ◦C***	***Critical cooling rate (K/s)***	***Tensile strength in MPa***	
			As delivered	***Hot stamped***
20MnB5	450	30	637	1354
BTR165	410	27	608	1478
8MnCrB3	---	--	520	882
27MnCrB5	400	20	638	1611
37MnB4	350	14	810	2040

Steel	***Martensite start temperature in◦C***	***Critical cooling rate (K/s)***	***Yield stress (MPa)***	
			As delivered	***Hot stamped***
20MnB5	450	30	505	967
BTR165	410	27	457	1010
8MnCrB3	---	--	447	751
27MnCrB5	400	20	478	1097
37MnB4	350	14	580	1378

The die is divided into a heating and a cooling zone. With the different die temperatures, the cooling rates different in different regions. Such that, different mechanical properties can be achieved in different temperature zones throughout the specimen. The parameters used in this method are shown in Table II.

TABLE II. Experimental process

Temperature of Cooling zone of tool [°C]	**Furnace Temperature zone[°C]**	**Temperature holding time[s] in press**	**Holding pressure[KN]**
12	860	16	6500
12	900	16	6500
12	950	16	6500

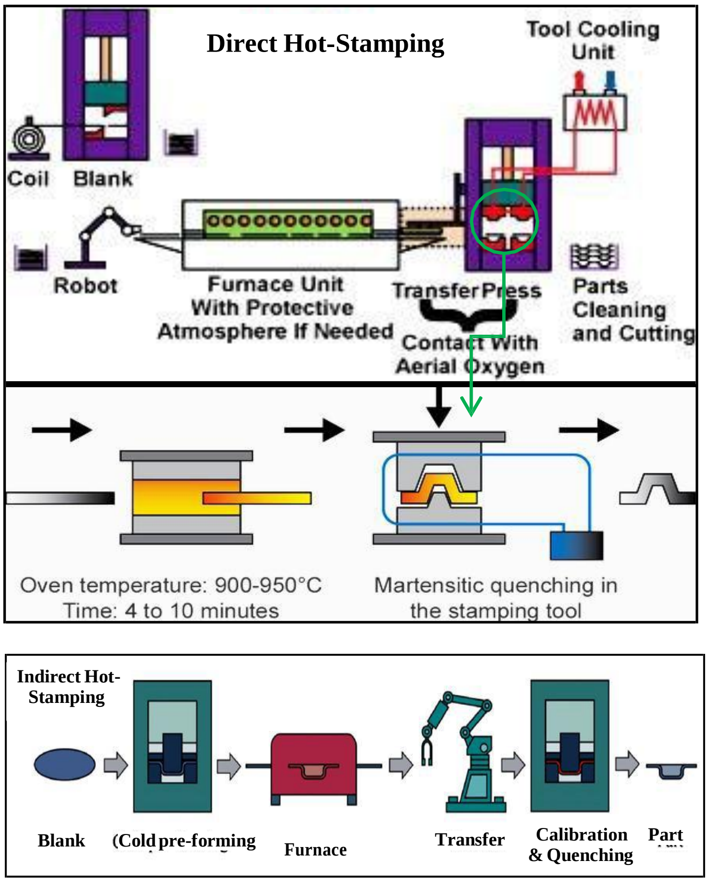
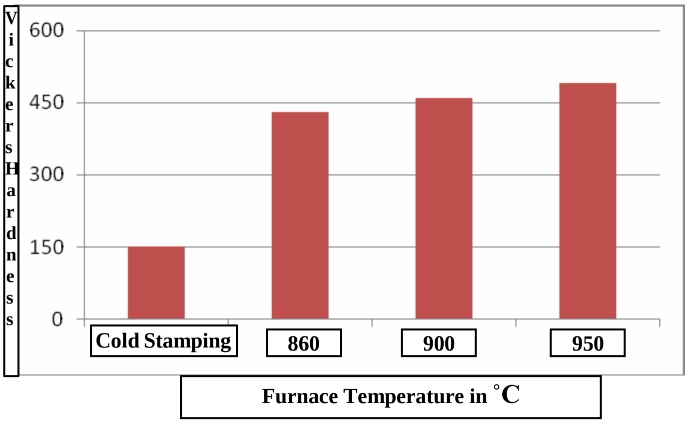


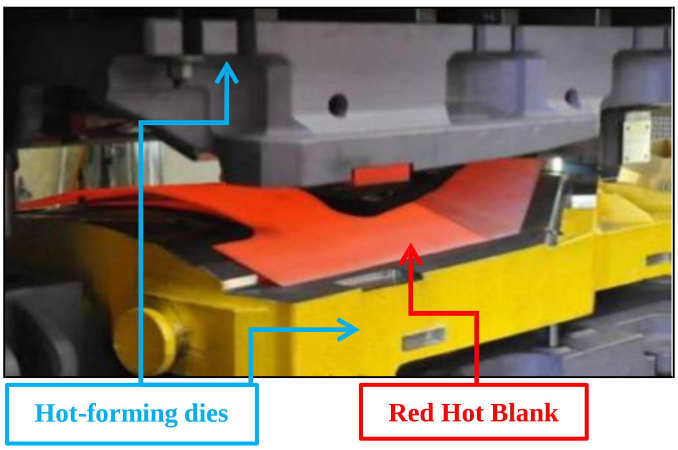
Fig. 1. Hot-forming process

Another method to get tailored properties is annealing the hardened specimen. The temperature of blank was set at 860, 900 and 950 °C and induction or gas heating was chosen. The Wolpart Vickers Hardness testing machine was used to test the hardness distribution and the universal tensile testing machine AG-IC 100kN is used to test the tensile strength as well as total elongation in different regions. Below chart shows hardness of part at cooling portion of die with different furnace temperature.



B. Hot-forming tooling development and methods:
Hot-forming dies dividing into a heating zone and a cooling zone (die partition) is also one method to get tailored properties, as shown in Fig. 2.When the hot blank is quenched in a die, its thermal resistance is released on temperature difference during the process of heat exchange between the blank and the die, thus affecting the cooling rate of the heated blank. When a hot blank is contacted with a cold die, the cooling rate is so large that austenite will be completely converted into ultra-high-strength marten site, resulting in high strength parts. However, when a heated blank is in contact with a hot die, the thermal contact resistance increases, the cooling rate of the component will be reduced or lower than the critical cooling rate (27 °C /s), beyond which the austenite transforms into marten site. Therefore, multi-phase microstructure comprising bainite and marten site is obtained with the minimised strength and enhanced plasticity.

Fig. 2. Dies for hot forming parts.



Annealing the hardened steel to get tailored properties is also one of the effective way in which marten site can be decomposed to other phases such as ferrite and carbides.

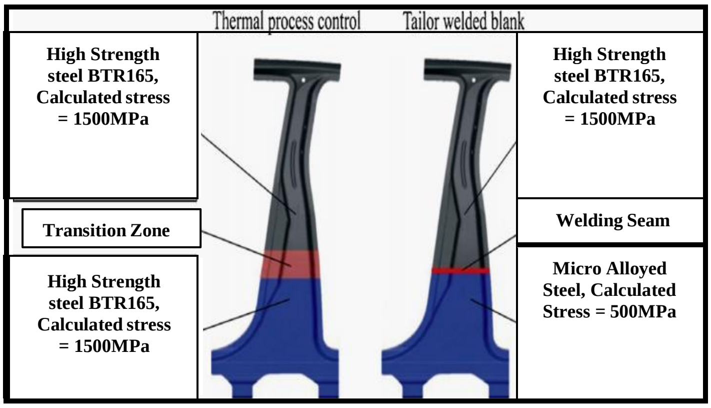


Fig. 3 hardness distribution

Annealing experiments have been performed to determine the optimal annealing conditions. To eliminate the bucking deformation after annealing process, the U type part has been chosen which stamped by the hot-forming die in Fig. 2 Heating temperatures and time was determined to produce sound product.

III. Results & discussions

A. Results of hot-forming die dividing into heating and cooling zones:

The hardness distribution of the heating zone, cooling zone and the transition zone at different temperatures is not similar. The hardness was tested by 430HV Vickers Hard meter.

When the die temperature in the heating zone is below 400 °C, the minimum hardness value of the part emerged in the transition zone. When the die temperature reached 400°C, the higher hardness in cooling zone gradually transfer to the lower hardness in heating zone, which coincides with the results of others .When the die temperature in heating zone was below 200 °C, the hardness in the heating zone failed to decline significantly, which stayed at 490-510HV as well as the cooling zone. When the die temperature increases up to 300 °C. The hardness in the heating zone declined from 510 HV to 450 HV. When the die temperature reaches to 400 °C, part hardness in the heating zone is reduced to as low as 325 HV. The heat transfer between blank and air in the transition zone results in the lower cooling rate, whose cooling performance is poor than that of contact heat transfer. What's more, the temperature of the air gap is affected by the hot-forming die in the heating zone, which will be largely improved, thus reduce the cooling rate in the transition zone. Consider the two factors; the lowest hardness value created in the transition zone.

However, when the die temperature riches up to to 400 °C, the temperature difference reduces and the cooling rate of the part in heating zone is lower than that of transition zone.
The stress- strain curves of the hardened steel in the cooling zone of hot-forming die and the softened steel in the heating zone with hot-forming die temperature of 400 °C. The tensile strength of the hot-formed hardened steel reaches up to 1600 MPa, while the total elongation is only 9.4%. When the die heated up to 400 °C, the tensile strength of hot-forming part in heating zone reduces up to 825MPa and the total elongation rise up to 10.8%. There is conclusion, by the method of die partition to obtained tailored Properties the tensile strength of part declines obviously while the overall total elongation fails to increase notably.

B. Results of annealing of hardened steel

Fig. 4 shows the physical map of annealed part and Fig. 4 shows the hardness distribution across overall transition zone at different annealing temperatures.

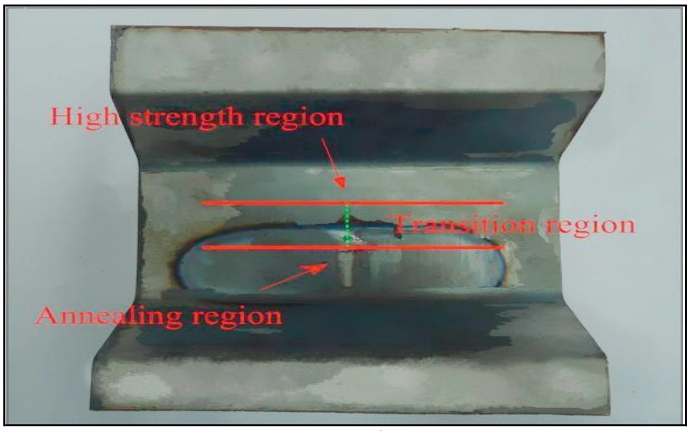


Fig. 4. Physical map of annealed part

With four different annealing temperatures utilizes, the higher hardness in high strength zone gradually
transferred to the lower hardness in annealing zone where the hardness of the part in annealing zone is less than 250HV. There is no matter how much the annealing temperature. By the hardness distribution curve, it has been shows that annealing temperature has little bit effected on the hardness value while the annealing zone reaches its lowest hardness value at the annealing temperature of 780 °C, indicates that the hardness does not reduced with the rise of annealing temperature.

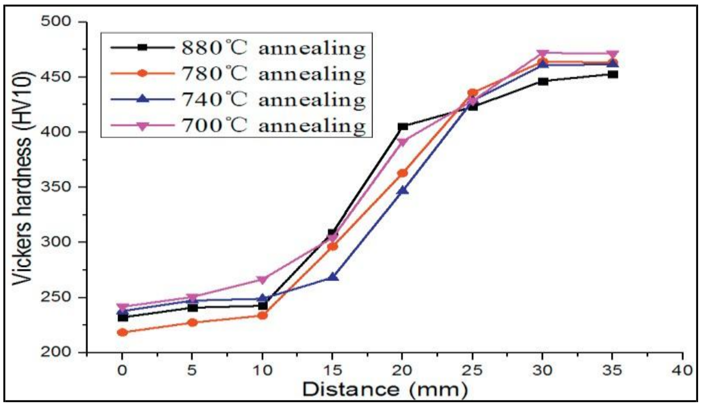


Fig. 5. Hardness curve across the transition zone at different annealing temperatures

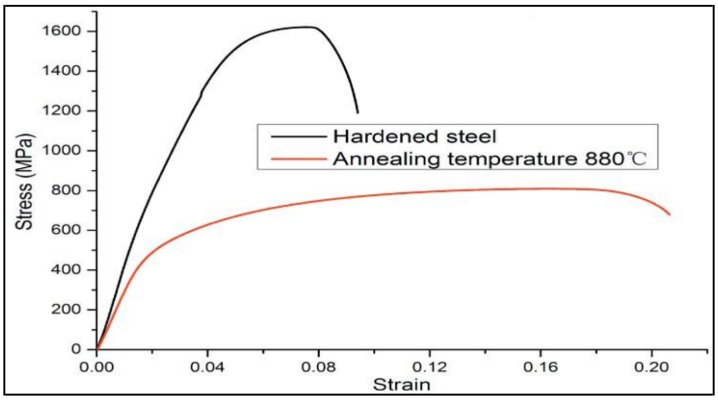
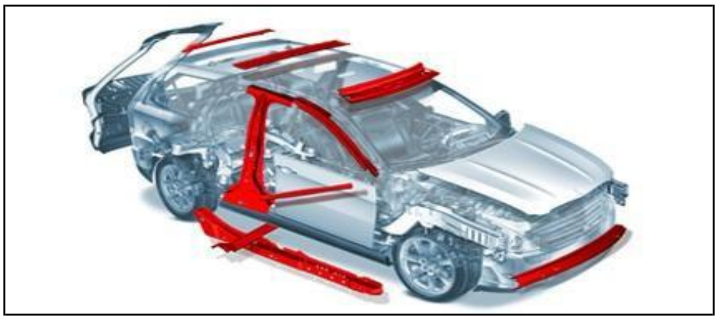


Fig. 6. Tensile curves of hardened steel and annealed part

Fig. 6 shows the tensile curves of hardened and annealed hot-form parts. The total elongation of annealed part reaches 18-20% while the tensile strength reduces up to 800 MPa. Compare the results of die partition. Shown in Fig. 3 and Fig. 4, Method of annealing to get tailored properties to brings better performance. However, annealing the hardened part to get tailored properties requires an extra process which is disputed in industrial community.



C. Surface finishing & Oxidation:

Hot-forming process done at very high(900-1000°C) temperature, there is partial oxidation of surface of hot-formed part formed, such that we get very rough surface finish &

aesthetical part quality is very poor, to overcome this problem we can provide inert gas or N2 with very less amount of LPG or CNG(3%-7%) in furnace.

D. Thermal characteristics:

The forecast of the mechanical properties of hot stamped parts by means of FE simulation requires an accurate modelling of the thermal phenomena during forming and quenching. The heat transfer coefficient h is responsible for the thermal behaviour and the respective cooling of the blanks throughout the whole hot-forming operation and can be influenced by the contact pressure and the temperature of the heated blank as well as the surface condition (scale thickness, roughness, coating thickness, etc.). As the mechanical properties of the base material BTR 165 are strongly dependent on the temperature, that is one of the most important parameter to be taken into account regarding FE modelling of thermally assisted forming .For to find out the heat transfer coefficient, a quenching tool has been developed by Hoff in 2007. The heated blank was quenched between water-cooled dies at a defined contact pressure. During the test, the temperatures of the blank and contact surfaces of the die were recorded. On the base of the measured parameters, the heat transfer coefficient is calculated in dependence

On the contact conditions using an analytical method according to

Newton's cooling law.

$T(t) = (T0 - T\infty)e(-h(A/cp\_V)t) + T\infty$ (5)

A= contact surface, cp= heat capacity, h= heat transfer coefficient, V= volume, t= time, T0= initial temperature, T∞: environmental temperature,_: density

The evaluation of the heat transfer coefficient has a function of the increased contact pressure shows the significant influence of the applied load on the heat exchange between work piece and die. Increase the contact pressure leads to an increase of the heat transfer. This effect is related to the increase in the effective contact surface between the two contact partners through smoothing, in particular of the case in the Al-Si coated Blanks. Consequently, more and more real metal to metal contact areas occur enforcing direct heat conductance effects, through thermal energy between the two contact bodies is transferred

IV. Conclusions and future work

In order to enhance the crashworthiness, energy absorption of the whole component as well as the safety performance, this work has performed hot forming of high strength steel with tailored properties by two methods. Dividing the die in heating zone and a cooling zone (die partition), the getting results distinguish with that reported in the current literatures, which required to be investigated in the future work. Meanwhile, the following basic disciplines may be concluded from the obtained results: (a) When the die temperature is lower than 300°C,the hardness goes up to its minimum value in the transition zone, while when the die temperature exceeds 400°C, the hardness exhibits gradient transition from the cooling zone of the die to the heating zone; (b) By the method of annealing, the hardness slight changes from high strength zone to annealing zone and the annealing temperature shows small influence on the hardness distribution; (c) Regardless of the reduction of tensile strength, the total elongation of annealed zone can reach up to 20.6% whereas the part in the heating zone can only obtain 10.8%. The results show that the process of annealing hardened hot-form part to get tailored properties achieves best performance.

In future corresponding experiments and numerical research will be perform to search & investigate the complex hardness distribution and find solution to get best performance with tailored properties.

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