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Hot Stamping Simulation and Austenite Decomposition Modeling of an Automobile Cross Member

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Abstract

Hot stamping is a process which simultaneously forms and quenches the hot blanks at the austenization temperature (900-1200 ^{0}C) to produce full martensitic Ultra High Strength (UHS) steel structure. The aim of this paper is to simulate the thermo-mechanical process of the hot stamping which consists of FEA (Finite Element Analysis) simulations by using LS-DYNA. The objective of the simulation is to model the austenite decomposition which yields the output of austenite daughter products' weight percentages, Vickers hardness, and yield strength of the steel. The results of this simulation are compared to the research of other people, shows the validaty of the FEM simulation.

Keywords: hot stamping, Ultra High Strength Steel, austenite decomposition modeling, daughter products;

1. Introduction

Hot stamping is a process to produce Ultra High Strength (UHS) automobile steel components without any spring back and decreased weight to improve safety factor. The yield strength and tensile strength of the hot stamping products can be significantly increased to 1000 MPa and 1500 Mpa, respectively. The most common UHS steel which is used on the market is Boron alloyed 22MnB5 steel.

This paper will simulate a hot stamping process of automobile cross member. The material which is used is 22MnB5 which parameters can be determined in the LS-DYNA keyword material 244

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*MAT_UHS_STEEL. The austenite decomposition modeling feature which is added in this keyword will be able to yield the output of each austenite daughter phase (ferrite, pearlite, bainite, and martensite) weight percentage along with the Vickers hardness and yield strength of the material.

2. Continuous Cooling Transformation (CCT) Diagram of 22MnB5

Continuous Cooling Transformation (CCT) diagram is a diagram that can predict the phase of iron-carbon alloy at certain temperatures that in the process of cooling with a certain number of cooling rate. The transformation starts after a cooling curve passes the intersection line of one phase to another phase. For the continuous cooling of the ultra high strength steel as shown in the Fig 1, there exist a critical quenching rate (25℃/sec), which represents the minimum rate of quenching that will produce a totally martensitic structure. This critical cooling rate, when included on the continuous transformation diagram will miss the nose at which the bainite transformation begins. The figure also defines that only martensite will exist at room temperature (20℃) for cooling rate that is greater than the critical; the next range of rate is the part when ferrite, bainite, and martensite will be produced at room temperature, the last range of rate is the part where only a composition of ferrite and pearlite will be produced at room temperature. the martensite start temperature Ms is 410°C. The circled numbers indicate the values of hardness in HV10 scale.

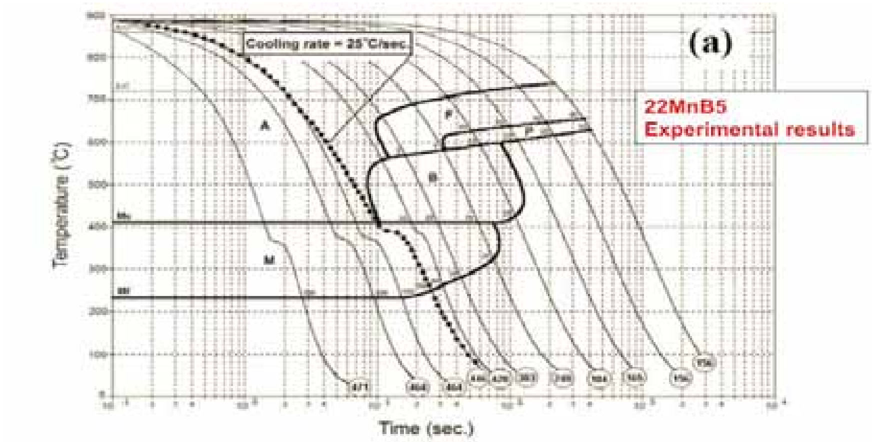


Fig.1. MAT_244 UHS Steel CCT Diagram [1]. A: Austenite; F: Ferrite; P: Pearlite; B: Bainite; M: Martensite

3. MAT_UHS_244

The material model of UHS Steel has been made in LS-DYNA to simulate the austenite decomposition modeling and also the effect of boron addition to the material yield stress and Vicker's hardness for any given design of hot stamping. This material is based on the Phd. Thesis by Paul Akerstrom and implemented by Tobias Olsson (ERAB). The input of the programming includes: 15 element constituents, latent heat, expansion coefficients, phase hardening curves, phase kinetic parameters, and Cowper-Symonds parameters. The output includes: austenite, ferrite, pearlite, bainite, and martensite phase fractions, Vicker's hardness distribution, and yield stress distribution.

The table1describes the % weight of each alloying elements in the UHS Steel. The HAZ (Heat Affecting Zones) composition is used to simulate the welding process, while in this current research, the Akerstrom alloy composition will be used.

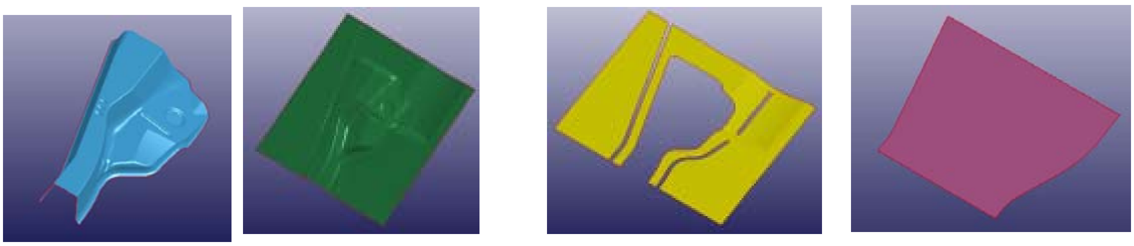
Table 1 Material Elements According to Several Researches [1]

	HAZ	Akerstrom	Naderi	ThyssenKrupp Max. values
B		0.003	0.003	0.005
C	0.168	0.23	0.230	0.250
Co				
Mo	0.036			0.250
Cr	0.255	0.211	0.160	0.250
Ni	0.015			
Mn	1.497	1.25	1.18	1.40
Si	0.473	0.29	0.220	0.400
V	0.026			
W				
Cu	0.025			
P	0.012	0.013	0.015	0.025
Al	0.020			
As				
Ti			0.040	0.05
S		0.003	0.001	0.010

The table1 describes the % weight of each alloying elements in the UHS Steel. The HAZ (Heat Affecting Zones) composition is used to simulate the welding process, while in this current research, the Akerstrom alloy composition will be used.

4. FEA Simulation Components

A cross member is an automobile component which is usually boxed and bolted across the underside of a motor vehicle to support the internal combustion engine or transmission. The cross member frame has to be strong enough as a suspension for the car to withhold the loads applied and to keep proper handling for the car and to keep body panels in alignment. The cross member must not deflect and high torsional strength to resist twisting. The cross member hot stamping components used in this simulation are shown in the Fig 2 below:



(a) (b) (c) (d)

Fig. 2. Components (a) Punch; (b) Die; (c) Holder; (d) Blank

The cross member components and assembly in this research are courtesy of Livermore Software Technology Corporation (LSTC), Livermore, CA, USA. The assembly of the components modeled in LS-DYNA is as follows (Fig 3):

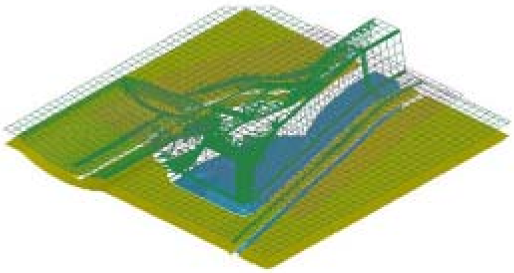


Fig. 3. Cross Member Hot Stamping Tool Assembly [5].

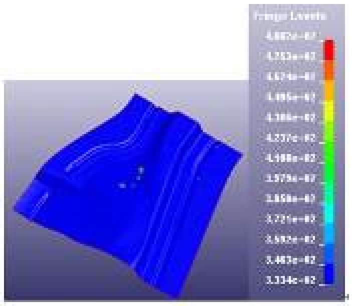


Fig. 4. The Final Temperature of the Blank at the Ending of Hot Stamping Process

The metal forming application in LS-DYNA will be used with the element formulation 2: Belytschko-Tsay and the material of the blank is MAT 244: UHS Steel. The frictions between each contact components are 0.125 and the contact type used is FORMING_ONE_WAY_SURFACE_TO_SURFACE.

After the determined time step is achieved, the material parameters such as pressure, temperature, hardness, yield strength, and the percentage of the austenite, ferrite, pearlite, bainite, and martensite phases can be known.

5. Simulation Process & Results

The beginning condition value of the yield strength is 111.5 MPa on the blank surface. In this condition the blank is fully austenite in composition. The beginning condition of the temperature is 1100 ℃ on the blank surface. This temperature achieved after the heating process to the temperature beyond the ferrite start temperature (1069.58℃ for MAT 244: UHS Steel) has been reached. After the forming process which is paired with the rapid cooling process is done, several results can be obtained such as figures shown below (Fig 4). For the temperature condition, the final temperature after the forming process is mainly 333.4℃ on the blank surface. This temperature condition is sufficient because the martensite transformation already started at the temperature of 680.143℃. The maximum temperature is reached in the red colored location of the blank which is 488.2℃.

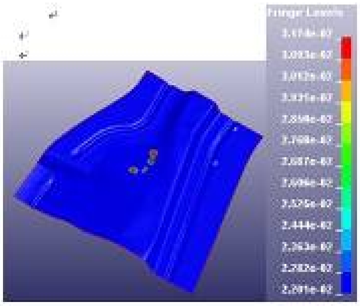


Fig.5. The Austenite Weight Percentage at the Ending of Hot Stamping Process

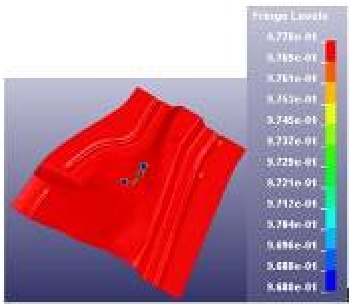


Fig. 6. The Martensite Weight Percentage at the Ending of Hot Stamping Process

The austenite percentage at the end of the process which has the temperature of 333.4℃ is shown in the figure below which is ranging from 2.201 x 10-2 % wt (blue) to 3.174 x 10-2 % wt (red). In most locations of the blank as shown in the Fig 5, the percentage of austenite is about 2.201 x 10-2 % wt.

The martensite percentage is ranging from 96.8 % x 10-2 % wt to 97.78 % x 10-2 % wt. The percentage of the martensite as can be seen in the Fig 6 shows the greatest amount of percentage and has a vast difference from the other phases. This is reasonable because at the current temperature 333.4℃ the martensite temperature had already started.

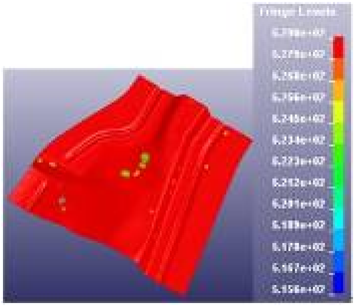


Fig.7. The Vickers Hardness at the Ending of Hot Stamping Process

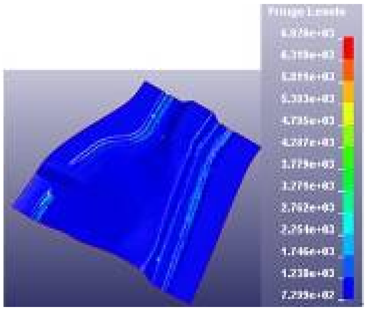


Fig. 8. The Yield Strength at the Ending of the Hot Stamping Process

The Vickers hardness of the blank is ranging from 515.6 to 529 HV but generally has the hardness value of 529 HV in most of the part. The result is shown in the Figure 7

Yield strength of the blank is mainly equal to 729.9 MPa in most area of the blank (Fig 8). This shows a greater increase of the initial yield strength of 111.5 Mpa. For the faster cooling rate of the hot stamping process, greater yield strength can be achieved.

6. Results Comparison

The results of Vickers hardness, weight percentage of ferrite, pearlite, bainite, and martensite will be compared to Dr. Arthur Shapiro's research to determine the reliability of this simulation results.

Table 2 Results of Dr. Arthur Shapiro's Research

Cooling rate [C/sec]	Vickers Hardness	Ferrite wt%
200	478	0.0001
100	472	0.0001
40	459	0.0002
20	376	0.0005
10	273	0.0018
5	174	0.0093
2.5	172	0.7023

Table 3 Results of Dr. Arthur Shapiro's Research (Cont'd)

Cooling rate [C/sec]	Pearlite wt%	Bainite wt%	Martensite wt%
200	0.0004	0.0008	0.9692
100	0.0009	0.0028	0.9668
40	0.004	0.0256	0.9416
20	0.0154	0.4819	0.448
10	0.0852	0.9015	0.0111
5	0.9906	0.0001	0
2.5	0.2976	0	0

In comparison, the results of this research are:

Table 4 Results of This Research

Vickers Hardness	Ferrite wt%
529	0.00007

Table 5 Results of This Research (Cont'd)

Pearlite wt%	Bainite wt%	Martensite wt%
0.0001	0.0001	0.9778

Based on the research result, it can be concluded that the cooling rate used exceeds the critical quenching rate (which equals to 25℃/sec according to the Fig 4-1), thus the final product is nearly a totally martensitic structure (97.78 %).

7. Conclusions

The simulation by using LS-DYNA models a cross member hot stamping process which can produce austenite decomposition modeling results. In other words, it will produce the results of weight percentage of each austenite daughter products phases (ferrite, pearlite, bainite, and martensite) and also the Vickers hardness (HV) and yield strength of the blank material. In this simulation, MAT_244 UHS Steel which is based on the PhD. thesis of Paul Akerstrom, implemented by Tobias Olsson (ERAB), and developed by Dr. Arthur Shapiro (LSTC) is used. This simulation yields the results of Vickers hardness of 529 HV; 0.00007 wt % ferrite; 0.0001 wt % pearlite; 0.0001 wt % bainite; 0.9778 wt % martensite; and 729.9 MPa of yield strength. It is proven that by the utilization of hot stamping, the yield strength of the material can be greatly improved (from 111.5 MPa to 729.9 MPa).

Based on the research result, it can be concluded that the cooling rate used exceeds the critical quenching rate (which equals to 25℃/sec according to the Figure 1), thus the final product is nearly a totally martensitic structure (97.78 %).

Acknowledgements

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