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Experimental Validation for Hot Stamping Process by Using Taguchi Method

Mohd Fawzi Zamri[1], Syh Kai Lim[2] and Ahmad Razlan Yusoff[3]
Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Malaysia

fawzizamri@gmail.com[1], fa10007.ump@ gmail.com [2], razlan@ump.edu.my[3]

Abstract. Due to the demand for reduction in gas emissions, energy saving and producing safer vehicles has driven the development of Ultra High Strength Steel (UHSS) material. To strengthen UHSS material such as boron steel, it needed to undergo a process of hot stamping for heating at certain temperature and time. In this paper, Taguchi method is applied to determine the appropriate parameter of thickness, heating temperature and heating time to achieve optimum strength of boron steel. The experiment is conducted by using flat square shape of hot stamping tool with tensile dog bone as a blank product. Then, the value of tensile strength and hardness is measured as response. The results showed that the lower thickness, higher heating temperature and heating time give the higher strength and hardness for the final product. In conclusion, boron steel blank are able to achieve up to 1200 MPa tensile strength and 650 HV of hardness.

1. Introduction

Global warming and greenhouse effect are becoming serious environmental issue to be discussed in recent years. Collective actions and International cooperation are needed to improve the weather today. The international agreement was made under the Kyoto Protocol of the United Nations Convention on Climate Change to reduce Carbon Dioxide (CO_2) emissions by average 8% [1]. Thus, vehicle weight reduction becomes the main objective in automotive industry because it reduces CO_2 emission and improves the fuel efficiency. Passenger safety improvement also must be considered in the design of lightweight chassis. In order to achieve the demand of lightweight structure and enhance passenger safety, ultra-high strength steels (UHSS) material like boron steels are increasingly used for automotive applications and intensive research is carried out to support this growing market.

The hot stamping also named as press hardening process, which is a combination of three phases: heating blank, part forming and part quenching [2]. Before hot stamping, tensile strength of boron steel is around 600 MPa. However, the steel sheet is heated and then transferred to press and rapidly quench. The tensile strength of stamped parts may be around 1500 MPa after hot stamping

[1] Email: razlan@ump.edu.my

process [3]. The thickness of sheet metal may be decreased in order to reduce the weight of vehicle structure parts. In hot stamping technology, the part with complex shape, light weight and high tensile strength is manufactured for automotive component such as A-pillars, B-pillars and side impact beams.

While, to strengthen the boron steel blank, it needed to undergo hot stamping processes. Chang et al. [4] studied the ability of boron steel to be quenched in close die to measure the hardness of the hardened boron steel. However, the effect of the austenization temperature and blank thickness of boron steel also in consideration to measure the hardness of hardened blank. A similar research finding by Merklein and Lechler [5,6] also point toward the blank with variable thicknesses were heated and quenched inside a tool made of metallic material with constant contact pressure of 40 MPa and the hardness of the formed parts were be measured by Vickers Hardness Tester. In 2011, Chang et al. [4] found that coated boron steel is capable to achieve 1500 MPa tensile strength after being hardened inside the tools. Nevertheless, the tensile strength of boron steel reduced as the austenization temperature is increased to more than 900ºC. In 2008, Lopez et al. [7] group investigated the strength of boron steel decreased due to its microstructure grains grew too large, after austenization temperature above 950ºC.

Hot stamping process began with obtaining of numerical simulation because it is a powerful tool used to analyse thermo-mechanical properties and process in hot stamping. In 2012, George et al. [8] developed a numerical model of partial quenching by using LS-DYNATM to predict the Vickers Hardness of formed B-pillar. However, far too little attention has been paid to the effect of heating temperature and time to improve tensile strength of boron steel from austenite to martensitic microstructure. Therefore, this paper mainly focus on the experimental observation of the hot stamping of different thickness boron steel at certain heating temperature and heating time, and validation to the experimental results with the ANSYS simulation for hot stamping by using Taguchi Method. Lastly, the final section of this paper will present the result of tensile strength and Vickers Hardness of different thickness boron steel in different heating temperature and time by using Taguchi Methods..

2. Methodology

2.1. Taguchi Method

As to evaluate relative contribution of hot stamping process parameters towards the final part of hot stamping product, Taguchi method was implemented in this project. This will results in establishing the optimum parameters of hot stamping process.

Table 1 shows Taguchi test matrix that was used in the experiment which are able to produce the final product with higher tensile strength and hardness. L_9 orthogonal array (OA) in Table 2 is the most suitable parameter to design experiment matrix for three factors with three levels. This L_9 array requires minimum number of tests in order to investigate the hot stamping process. As for the total, it can be known either by using a table or MINITAB Software. There are several factors that are important in hot stamping product. The factors are blank thickness, heating temperature and heating time.

Table 1. Factor and Level Description

Factor	Factor Description	Level 1	Level 2	Level 3
A	Blank Thickness (mm), a	1.8	2	3
B	Heating Temperature (°C), b	800	900	950
C	Heating Time (min), c	4	6	8

Table 2. L_9 Test matrix

DOE	**Factor**		
	A	B	C
1	1.8	800	4
2	1.8	850	6
3	1.8	900	8
4	2	800	6
5	2	850	8
6	2	900	4
7	3	800	8
8	3	850	4
9	3	900	6

2.2. Experimental Setup

The hot stamping tool is installed on the hydraulic press machine with 10 tonnes of capacity. Based on Figure 1a, hydraulic press machine is used as to apply 20MPa of pressure to the hot stamping tool. The value of pressure is calculated by using equation P = F/A and equation A = $\pi r2$. The furnace used to heat up the boron steel blank to the austenization temperature. Next, as to cool down the hot stamping tool, the chiller is used as to maintain the initial tool temperature at 18°C. Hot stamping tool was used to quench the boron steel blank, as shown in Figure 1b.

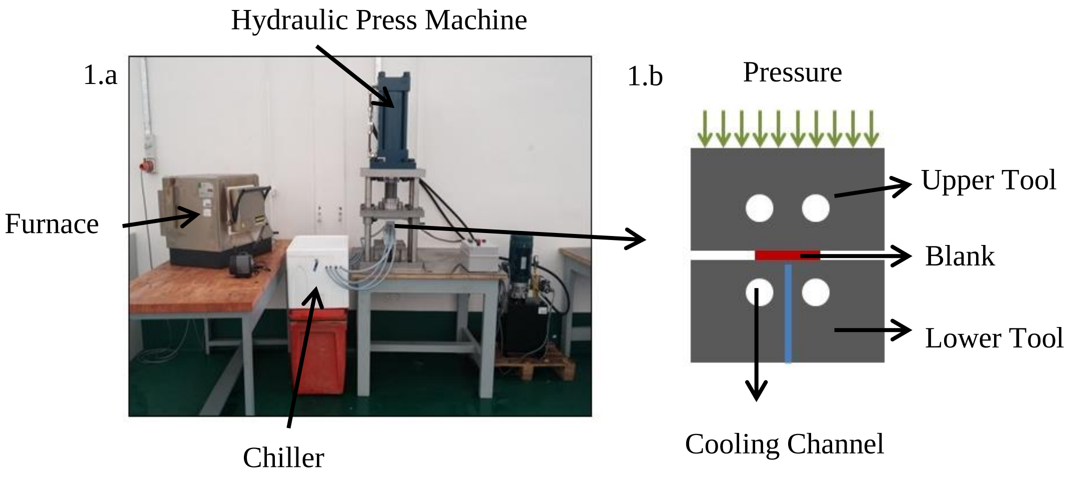

Figure 1. a) Hot Stamping Experimental Setup b) Schematic diagram of hot stamping tool

Boron steel is heated at temperature 800°C, 850°C, 900°C and placed in the furnace for 4, 6, 8 minutes respectively. Then, the specimen is transferred quickly from the furnace to hot stamping tool as to avoid the specimen cooled before pressing process is done. Hot stamping tool is closed for 10s with the specimen inside at initial tool temperature of 32°C. Steps above are repeated using different thickness of boron steel blank. Next, the strength of final product is measured using Universal Tensile Machine (UTM) for the tensile strength value and Vickess 402 MVD for the hardness value.

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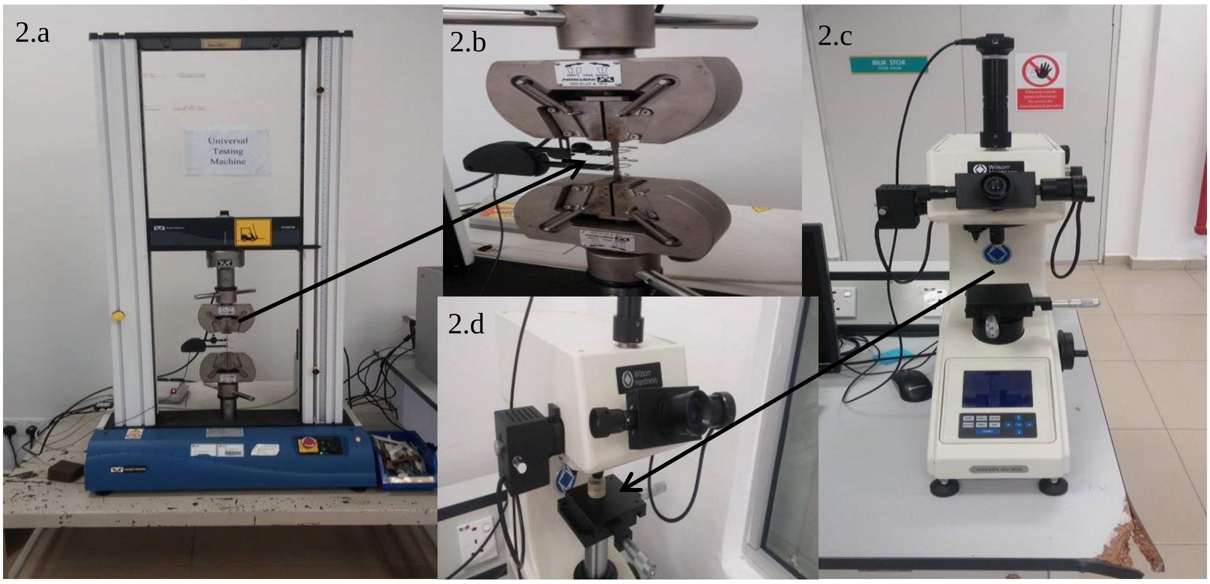

Figure 2. a) Universal Tensile Machine (UTM), Instron 3360 b) Tensile Test Specimen (E8M04) c) Wilson Hardness Vickerss 402 MVD d) Indent X40 Plan 40/0.65

The value for the tensile strength and hardness were obtained after conducting the experiment for all nine DOE. Each result represents one parameter of hot stamping process in the OA as shown in Table 3 which summarizes the tensile strength and hardness for boron steel blank under constant of thickness, heating temperature and heating time. All the results were analysed by conducting the main effect, S/N Ratio and (ANOVA).

Table 3. Result of experiment

DOE	Factor			Result	
	A	B	C	Tensile Strength, MPa	Hardness, HV
1	1.8	800	4	696.604	372
2	1.8	850	6	1001.43	497
3	1.8	900	8	1034.745	619
4	2	800	6	515.598	179
5	2	850	8	499.962	238
6	2	900	4	590.817	218
7	3	800	8	482.814	215
8	3	850	4	462.095	204
9	3	900	6	642.154	294

3. Result and Discussion

3.1. Main Effect

Table 4 summarizes the average main effect for tensile strength and hardness which obtain from each factor i.e. A, B, and C array each level (Level 1, level 2 and level 3). The main effect graph for tensile strength and hardness for boron steel blank under constant of thickness, heating temperature and heating time are shown based on result in Table 3. The quality of characteristics analysis in the experiment result was the higher is better for both tensile strength and hardness in setup the hot stamping process parameter. From Figure 7 it can be observed that the parameters and their levels of combination for tensile strength are A_1, B_3 and C_2 and for hardness, the combinations are A_1, B_3 and C_2.

Table 4. Level average for main effects

Symbol	Parameters	Average Main Effect							
		Tensile Strength				Hardness			
		Level 1	Level 2	Level 3	Rank	Level 1	Level 2	Level 3	Rank
A	Blank Thickness (mm)	910.9	535.5	529.0	1	496.0	255.3	264.7	1
B	Temperature (°C)	565.0	654.5	755.9	2	211.7	313.0	323.3	2
C	Heating Time (min)	583.2	719.7	672.5	3	237.7	377.0	357.3	3

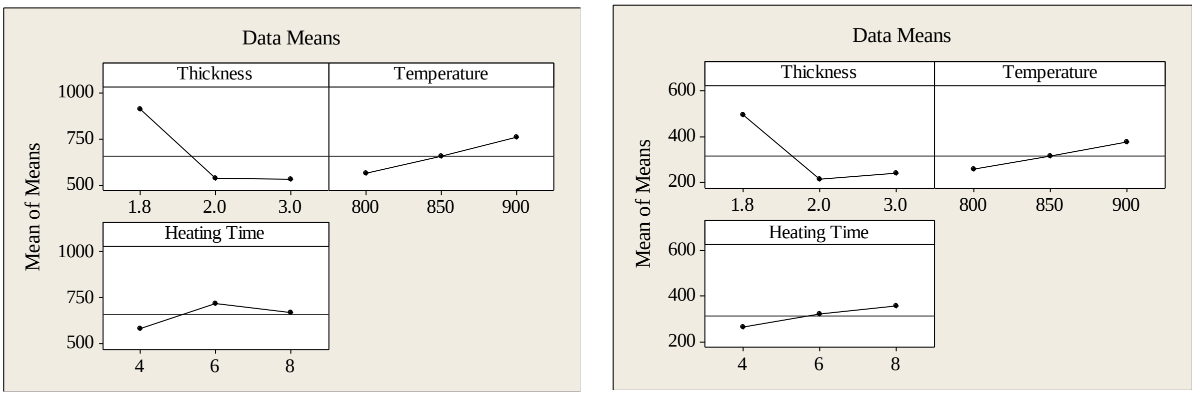

Figure 3. Main effect graph for tensile strength and hardness

3.2. Analysis of S/N ratio

Signal Noise Ratio (S/N Ratio) is the ratio between signals to noise. Signal is a desire value and noise related to undesire during conducting the experiment. The tensile strength and hardness respond or variable respond is desired value and the other effect such as transfer time, stamping time and etc is undesired value or noise. Basically there have three categories of S/N ratio, such as nominated as the better, smaller is better and larger is better. In this result, a larger is better used for both respond. The S/N ratio equations for both respond are shown in below.

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}\right] \tag{1}$$

Where *yi* is the respond value for *i* th test and *n* is the number of test. Thus, the S/N ratio is calculated from the experiment is using the Equation 1. Then, all value for S/N ratio is listed in Table 5. From the table, it show the 60.2967 dB is higher value for S/N ratio of tensile strength and 55.8338 dB is the highest value for S/N ratio of hardness. Compared to main effect, it shows that the optimum level for tensile strength and hardness give the diff result for S/N ratio analysis.

Table 5. S/N ratio response for tensile strength and hardness

DOE	Larger is better		Larger is better	
	Tensile Strength	S/N Ratio (dB)	Hardness	S/N Ratio (dB)
1	696.60	56.8597	372	51.4109
2	1001.43	60.0124	497	53.9271
3	1034.74	60.2967	619	55.8338
4	515.60	54.2462	179	45.0571
5	499.96	53.9787	238	47.5315
6	590.82	55.4291	218	46.7691
7	482.81	53.6756	215	46.6488
8	462.10	53.2946	204	46.1926
9	642.15	56.1528	294	49.3669

3.3. Analysis of Variance (ANOVA)

In this study, the ANOVA will examine the influence of parameter for hot stamping process toward strength of boron steel blank. Table 6 shows the ANOVA get from MINITAB software. The result show the A is more significant parameter which is the value of F-ratio is 28.70 higher than B and C.

Table 6. ANOVA for tensile strength

Source	DF	Seq SS	Adj SS	Adj Ms	F	P
A	2	286869	286869	143434	28.70	0.034
B	2	54735	54735	27368	5.48	0.154
C	2	28858	28858	14429	2.89	0.257
Error	2	9995	9995	4998		
Total	8	380457				

S = 70.6936 R-Sq = 97.37% R-Sq(adj) = 89.49%

Table 7 shows the result of ANOVA for the hardness of boron steel blank. The significant parameters are same with the result for Anova of tensile strength value. The A shows the influence parameter more affect to the quality of hardness for boron steel blank. It shows the F- ratio for the A is 86.29.

Table 7. ANOVA for hardness

Source	**DF**	**Seq SS**	**Adj SS**	**Adj Ms**	**F**	**P**
A	2	148258	148258	74129	86.29	0.011
B	2	22224	22224	11112	12.93	0.072
C	2	13185	13185	6592	7.67	0.115
Error	2	1718	1718	859		
Total	8	185385				

S = 29.3106 R-Sq = 99.07% R-Sq(adj) = 96.29%

From Table 6 and 7 above, both results from tensile and hardness experiment indicates source A is the most significant factors as it results higher F-ratio compared to source B and C. Thus it can be concluded that different volume of material will result different parameter in hot stamping process.

Table 8. Result of responding value from Taguchi method

DOE	Factor			Result	
	A	B	C	Tensile Strength, MPa	Hardness, Hv
2	1.8	850	6	1001.43	497
New	1.8	900	6	1050.56	602
3	1.8	900	8	1034.745	588

4. Conclusion

In this study, Taguchi method is applied in validating the best level to be used in the experiment as to get the best responding value. The suggested value from the Taguchi method is A_1 B_3 C_2, while from the experiment is A_1 B_3 C_3. Since the both responding value is different, new experiment parameter need to conduct, as to prove the result of Taguchi is valid. From Table 8 it shows that the responding value from the Taguchi method gives the better result for tensile strength and hardness. So, it was found that the strength of boron steel is increase with the increasing of temperature and heating time, but the strength will slightly reduce if the heating time is more the heating point of boron steel [4,8].

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