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Effect of initial blank temperature in hot press forming towards 22MnB5 springback failure

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ABSTRACT

The springback failure of boron steel (22MnB5) in hot press forming (HPF) process was characterized under bending and membrane conditions. Springback failure happens due to the impact of thermal restoring moments and quenching rate of hot press forming process which causes dimensional deviation in final formed parts. Hot press forming on U–shaped boron steel parts were experimented and simulated to study the effect of initial blank temperatures on springback failure. ANSYS Workbench was used to simulate the processes in order to consolidate the knowledge of springback. The validated numerical simulation model was used in analyzing the stress and strain distributions along the formed part in the FE models. The results specify the effect of various preheated temperature of 22MnB5 blank toward springback occurrences. Measurement results on the bending angle of the stamped workpiece shows increment of bending angle and springback failure severity as the preheated temperature decrease. Simulation results determined that as the preheated temperature increased, the formability of boron steel increased while the stress within the sheet metal decreased. The study managed to signify and predict the phenomenon of springback in relate to preheating temperature while identifying proper processing variables in hot press forming process.

Keywords: Hot press forming; ultra-high strength boron steel; springback, ANSYS workbench.

INTRODUCTION

Weight reduction in vehicles had been prioritized by manufacturers since a decade ago. One of the solution to reduce vehicle weight was to apply Ultra-High Strength Steel (UHSS) parts onto the vehicle. The high strength to weight ratio on this part ensure weight reduction while maintaining the crashworthiness of the vehicle [1]. The parts are formed using novel process known as the Hot Press Forming (HPF) [2]. In HPF, 22MnB5 blank is heated and kept at a temperature of 950ºC which causes a formation of homogenous austenitic microstructure within the material [3,4]. The blank microstructure before the heating took place is ferritic-pearlitic microstructure. Afterward, the blank is transferred to the press in which it was press formed and quench simultaneously. Effective quenching rate of at least 27 ºC/s is required in order to fully transform the austenitic microstructure in 22MnB5 to a martensitic microstructure. The final formed parts almost tripled its strength level after the process with value of more than 1500 MPa [5]. The use of HPF process with its efficient quenching ability and the good formability properties of 22MnB5 at elevated temperature ensure production of complex sheet metal parts with accurate geometry and high strength-to-mass ratio [6]. 22MnB5 parts include frame structures such as A-Pillar, B-Pillar, impact beam, rear and front bumper [7]. However, hot press forming process is a highly complicated manufacturing process which its results may easily be affected by numerous parameters such as the strain and strain rate path of the material formed, preheating temperature of the material and evolution of material microstructure based on the quality of quenching phenomenon [3]. Studies had concluded that 22MnB5 is the only steel grades able to achieve fully martensitic microstructure after hot stamping and water-cooled tool quenched [8]. It's also shows that the formation of martensite during cooling of 22MnB5 blank usually begins at 425ºC and ended at 280 ºC where the material achieves full martensitic microstructure [9]. Henceforth, the preheating of 22MnB5 had to be sufficient in order to ensure high quenching rate while reducing springback formation during forming of the material. 22MnB5 are often characterized with higher strain hardening and higher strength compared to mild grades. Therefore, when 22MnB5 are formed to a certain strain level the observed springback is higher than that of mild steel [10] .

Formation of springback error in forming industries was not uncommon and quite frequent even in HPF process. Springback is a phenomenon which the material undergoes elastic recovery after forming and the tool loads removed [11]. Springback causes shape deviation from the design intended geometry. Common modes of springback include bending (angular change), membrane (wall curl), hybrid and twisting [12]. Abundances in previous studies on springback had helped in predicting and identifying the springback formation easily. Study on forming parameters such as the effect of holding force, bend location, punch velocity and punch angle parameters had been carried out with significant results in its springback phenomenon occurrence [13-17]. Both experimental and simulation studies were performed in relate to springback. Experimental studies by Sutasn and Pakkawat (2016) analyse the bending mechanism and springback characteristic especially in the offset Z-Bending process [18]. Several numerical studies develop an analytical model for predicting springback in sheet metal forming [19] and some studies focus on reducing springback phenomenon through finite element method [20-23]. Most of the study only emphasized in cold forming condition and focused on parameters such die gap, die radius, punch angle, rolling direction, blank thickness, velocity and holding force [13,24]. Study on springback in HPF was lacking especially in parameter such as preheating temperature of sheet metal blank. Hence, a study on determining the effect of blank initial temperature towards the springback defect in HPF was proposed. The study emphasized on the alteration in the pre-heating temperature of the 22MnB5.

MATERIALS AND METHODS

Blank Material Preparation

Boron steel (22MnB5) blank with the dimension of 145 mm×70 mm×1 mm was hot press formed in this experiment. Chemical composition of boron steel was shown in Table 1. The material properties of boron steel were shown in Table 2.

Table 1. Chemical composition of boron steel 22MnB5 (in wt %). [8]

Element	C	Mn	Si	Ni	Cr	Al	Cu	Ti
wt%	0.221	1.29	0.28	0.013	0.193	0.032	0.01	0.039

Table 2. Material properties of boron steel 22MnB5. [25,26]

Properties	**Value**
Density	7.83 g/cm3
Modulus of Elasticity	100 GPa
Poisson Ratio	0.3
Coefficient of Thermal Expansion	$13x10^{-6}$ m/m°C
Tensile Strength	600 MPa
Yield Strength	435 MPa

Experiment Setup

In the experiment conducted, the sheet metal was transferred into heat treatment furnace to undergo austenization. The furnace model is THERMCONCEPT-LAC KM225/13, with maximum operating temperature of 1280 ºC and nominal heat input of 29 kW. Before transferring the boron steel, the furnace was heated up to a temperature of 950 ºC. The 22MnB5 blank was then heated up until it achieved austenization stage (above 900°C) before being transferred to the hydraulic press machine with water cooling tools [27, 28]. In this experiment, the duration of transferring the heated sheet metal to the press work table stamping is crucial and best to be at the lowest time possible. This is because the temperature of sheet metal dropped unceasingly once the furnace lid is opened and the sheet metal keeps experience heat loss during transfer from furnace to pressing machine. Figure 2 shows the experimental setup involved within the study. Application of a K-Type Thermocouple determined the temperature changes during the HPF Process.

Before the hot press forming started, the inserts that made of H13 hot work tool steel were installed on the surfaces of punch and die as shown in Figure 3. These inserts played the role as determining the profile or dimension of the workpiece, different profile can be pressed by just changing the inserts without altered the punch and die. Note that the punch and die also made of H13. The punching force of 100kPa was applied in this stage. The sheet metal was put onto the die as quick as possible. However, the heated sheet metal must be located accurately on the die with minimum skewness. The HPF process lasted for around 7 seconds.

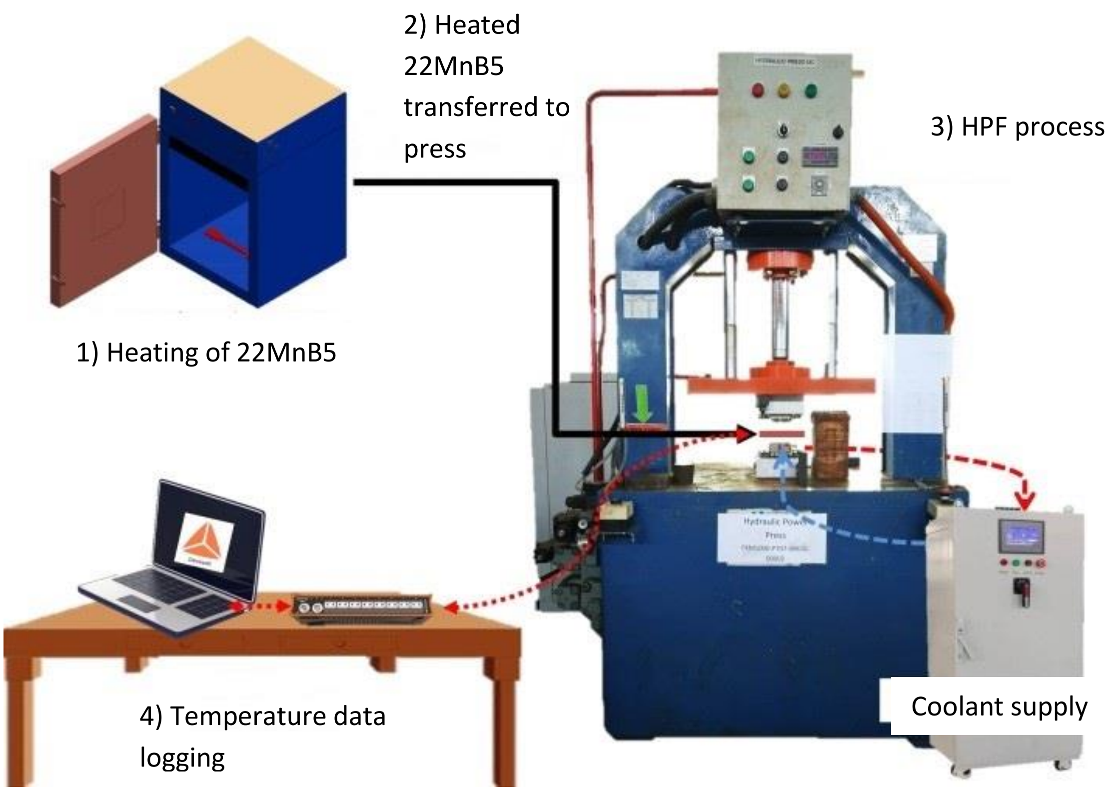

Figure 1. Experimental setup of boron steel 22MnB5 test.

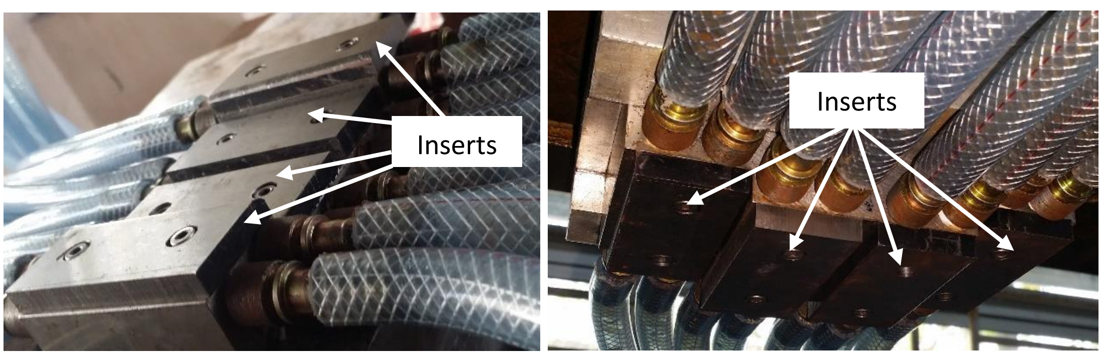

Figure 2. Inserts installed on the punch and die.

Quenching is a process where the sheet metal stamped at high temperature was cooled rapidly to obtain certain properties of material. Mostly, it was used to make material harden. The quenching process follow up just the stamping process have started. The water of 18 ºC were being flowed into the cooling channels. Figure 4 shows the heated sheet metal that readily be stamped, which already located on the die.

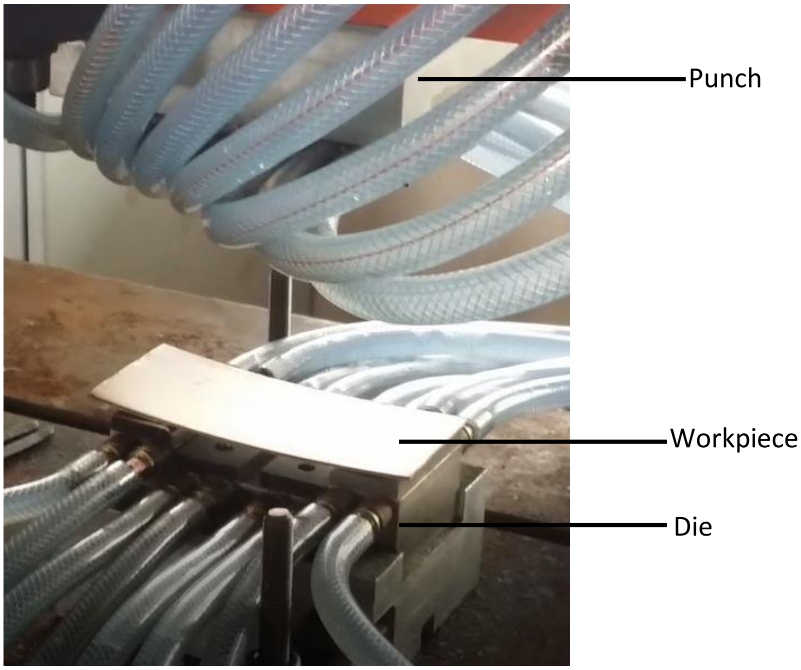

Figure 3. Sheet metal readily be stamped.

Numerical Simulation Model

ANSYS Workbench Transient Structural was used to simulate the hot press forming process in order to study the variation of stress and deformation within the blank during stamping process took place. Within Transient Structural analysis, five processes must be executed one by one, which are Engineering Data, Geometry, Model, Setup and Results. Within Engineering Data, both blank and die material (boron steel 22MnB5 and H13) must be created for further application. For the geometry of the hot press forming model, including punch, die, inserts and workpiece, were prior to be done in Solidworks, then imported into ANSYS Workbench, the HPF model after being imported into ANSYS Workbench was shown in Figure 4.

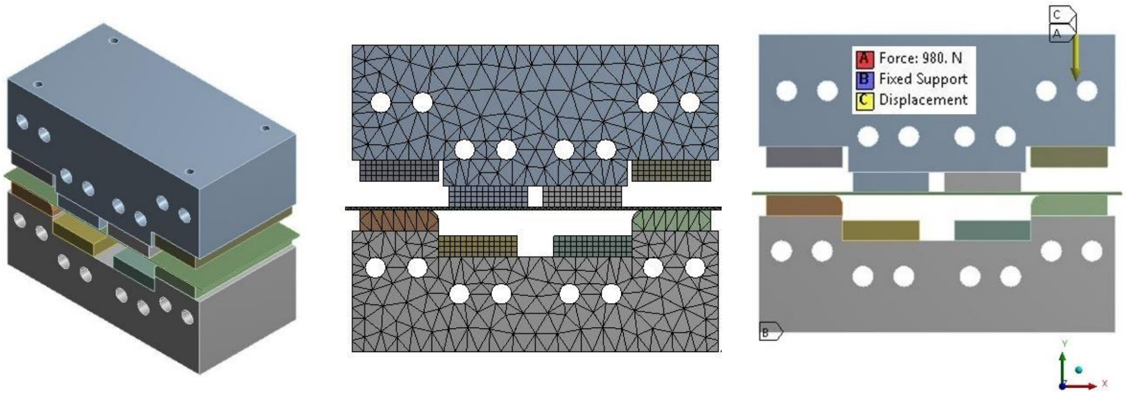

Figure 4. Geometry model in ANSYS Workbench (a) Geometry model generated in ANSYS, (b) Meshing condition of model, (c) Loading and boundary condition.

Within the 'Model' process, the material of die and workpiece were assigned to H13 and 22MnB5, which created at 'Engineering Data' stage. Meshing can also be done in this part. For the boron steel workpiece, 'patch conforming' method and tetrahedrons element was applied to ensure it can deform flawless and obtain a better geometry. For the punch, die and inserts, default meshing have used since the study is concerned on the springback occurrence within workpiece only. Through the meshing, 112045 nodes and 41264 elements have generated for the overall model. As proceed to the Setup part, which is relevant to the key parameters like punch force, blank holder force and initial temperature of sheet metal. First, the initial temperature of the thin plate is given at 900 °C, which indicate the sheet metal is heated from furnace. Then, the parameters are added one by one. The main parameter is punch force act on the sheet metal (downward direction), with 980N, which is converted from 100 kPa. Displacement must be applied on the punch to limit its moving distance. By measuring the distance between the surface of punch and die, 10mm is the distance moved by the punch. The fixed support is applied to the bottom surface of the die to prevent any movement due to the moving punch. Eventually, in 'Results' stage, two kind of solutions were selected as desired results, which were 'Maximum Principal Stress' and 'Directional Deformation'. For directional deformation, X, Y and Z orientation were evaluated for further analysis and discussion.

Measurement and Analysis of Springback Occurrence in Workpiece

From the hot press forming experiment conducted, the workpiece obtained have used to study the springback condition. The bending angles at the both side of sheet metal was obtained by tracing the bending profile of stamped workpiece, with the aid of ruler, protractor and plain paper, illustrated in Figure 5. From the ANSYS Workbench simulation, the workpiece after deformed into shape have used to measure bending angle, which using the same procedures from the experimental works.

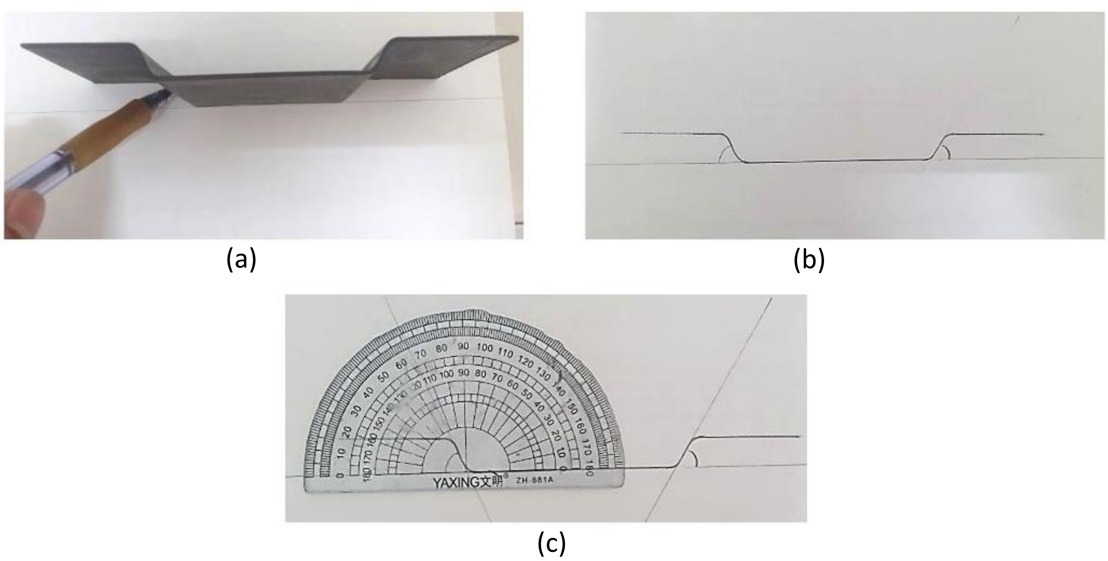

Figure 5. Procedures of measuring the bending angles of stamped workpiece: (a) tracing the bending profile, (b) sketched bending profile, (c) measuring of bending angles.

RESULTS AND DISCUSSION

In order to compare springback behavior as a function of forming conditions, the positional coordinates of simulation result models at the edge were extracted from the output and plotted. The predicted springback behavior of three workpieces as formed part with different pre-heating blank temperature of 28°C, 550°C and 900°C were compared and shown in Figure 6, respectively. Bending profile of these parts was acquired to conduct springback analysis, as illustrated in Figure 7. Based on the bending profile obtained, 28 °C workpiece (red color) did not achieve perfect geometry as compared to the workpiece with temperature of 900°C (black color). As indicated in blue color frame, the workpiece of 28°C was unable to bend towards horizontal line.

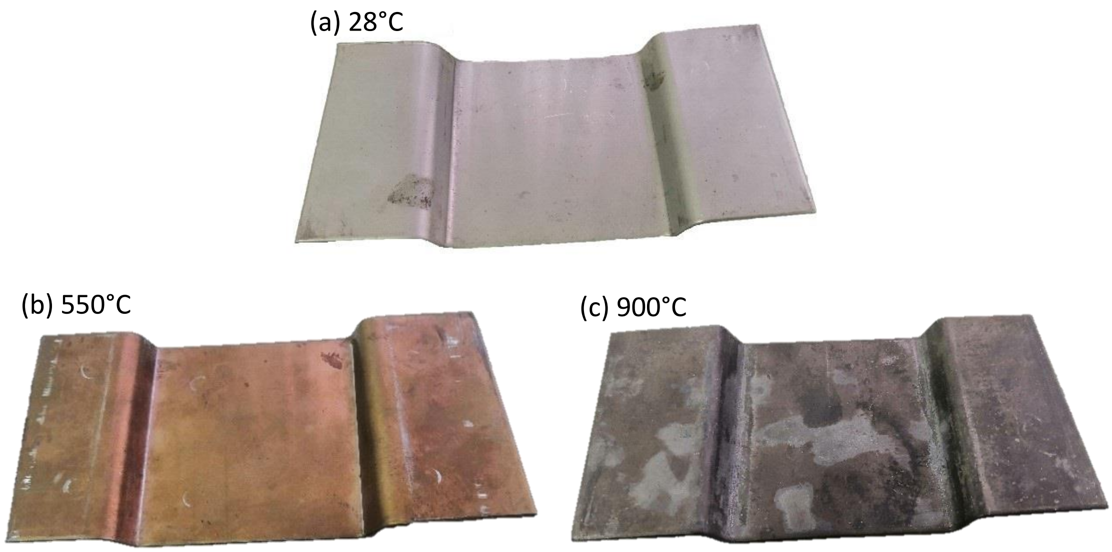

Figure 6. As-formed part under different pre-heating temperature.

The most significant difference was indicated by difference of height of 28°C and 900°C workpiece. Springback phenomenon occurred have caused 28°C workpiece obtained bigger height than that of 900°C workpiece. Through the experiment work, the results claimed that hot press forming process can overcome springback and low formability issues [25]. Note that three pieces of workpieces have different color, due to the coating of Al-Si layer that still adhered on 28°C workpiece; whereas for 900°C workpiece, the coating was activated steel diffusion process, when undergo austenization process in high temperature furnace [26].

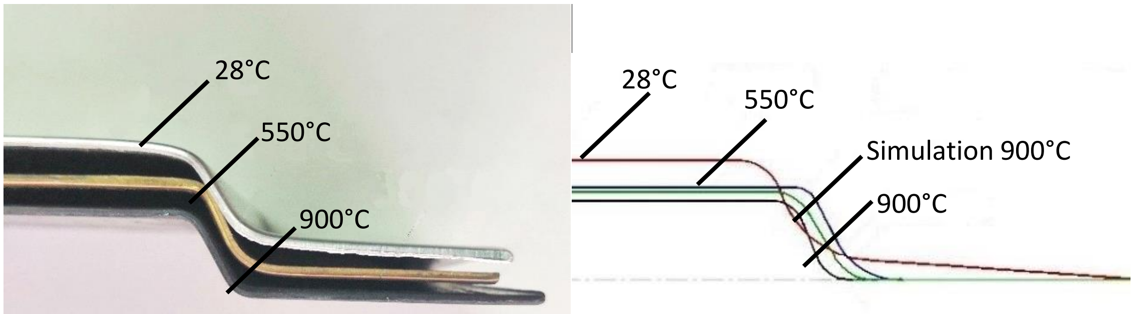

Figure 7. Bending angle of workpieces under different pre-heating temperature.

Numerical simulation model of hot press forming process by the application of ANSYS 16.0 Workbench software was constructed to validate the experimental data based on the geometry, i.e. bending angle of stamped workpiece, as shown in Figure 6 and 7. Also, in Figure 7, both experiment and simulation for a workpieces of 900°C bending profile were illustrated in green and black color. The workpiece of 900°C was selected for data validation. As observed from Figure 8 and Figure 9, both the bending angles did not have the same value, which might due to the misfeed of blank material and no blank holder to hold the blank in appropriate position [29]. Table 3 summarized the measured angle of both experimental and simulation result. Error of 9.23% was detected at the bending angle in simulation and experimental 900°C workpiece.

Figure 8. Bending angles of sheet metal by hot press forming experiment.

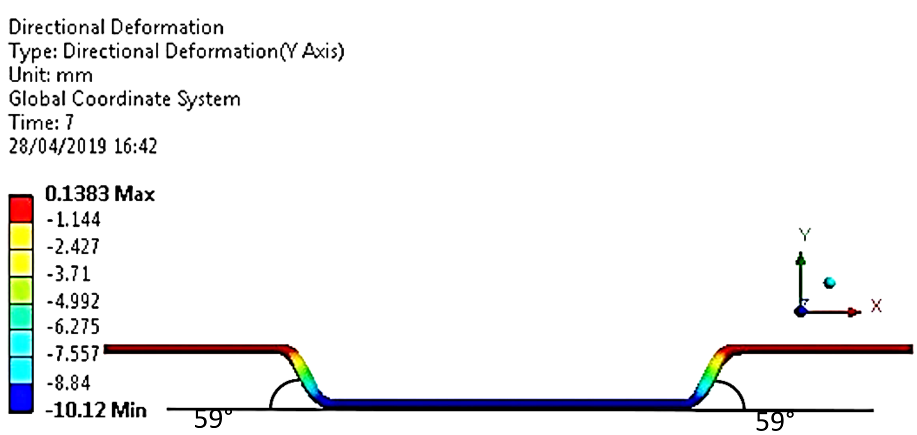

Figure 9. Bending angles of sheet metal by ANSYS transient structural.

Table 3. Summarized result for both experiment and simulation.

	Left	Right
Experiment 900°C angle	65°	58°
Simulation 900°C angle	59°	59°
Experiment 550°C angle	64°	62°
Simulation 550°C angle	61°	61°
Experiment 28°C angle	63°	68°
Simulation 28°C angle	64°	64°

Figure 10 shows the deformation data at X, Y and Z orientation acquired from ANSYS Transient Structural analysis. Based on the orientation, X-axis have the largest deformation, which indicated the blank have increased its length in X-direction after being hot stamped. Y-axis (positive orientation) have the smallest deformation due to the force applied in negative Y direction that caused the blank did not have significant increase in positive X-axis deformation. When comparing the deformation (Y and Z orientation) by mean of temperature, the 900°C have the highest value. This indicated that 900°C provide higher formability to the workpiece, and resulting the workpiece did not have high tolerance from desired geometry. In summary for Figure 10, high pre-heating temperature have granted boron steel blank high formability that can formed into desired geometry without large dimension tolerance [30].

From the ANSYS simulation analysis, the maximum principal stress and deformation of the workpiece with different pre-heating temperature and process duration were obtained and expressed in graphs shown in Figure 11. First, when observing at the stress trend, it was determined that the maximum principal stress increased with hot press forming process duration. As the HPF proceed, the maximum principal stress has gradually reached the steady state, as the principal stress value did not have any significant change in the magnitude. This phenomenon indicated that the stamping process was finished as the boron steel blank have totally formed up into the desired geometry and further force applied would not deal any stress increment on the workpiece. Maximum principal stress of 28°C workpiece recorded the highest value among the others showing the poor ductility in its structure. Workpiece at elevated temperature enters austenite state within its microstructure. This increases the ductility of workpiece and are able to deform without large effort. This explained why 900°C workpiece have the lowest stress value. As the quenching process took place, the ductility gradually reduced with temperature, and increased in maximum principal stress magnitude. In summary, as the workpiece temperature reduced, ductility reduced and resulting the increased of maximum principal stress value.

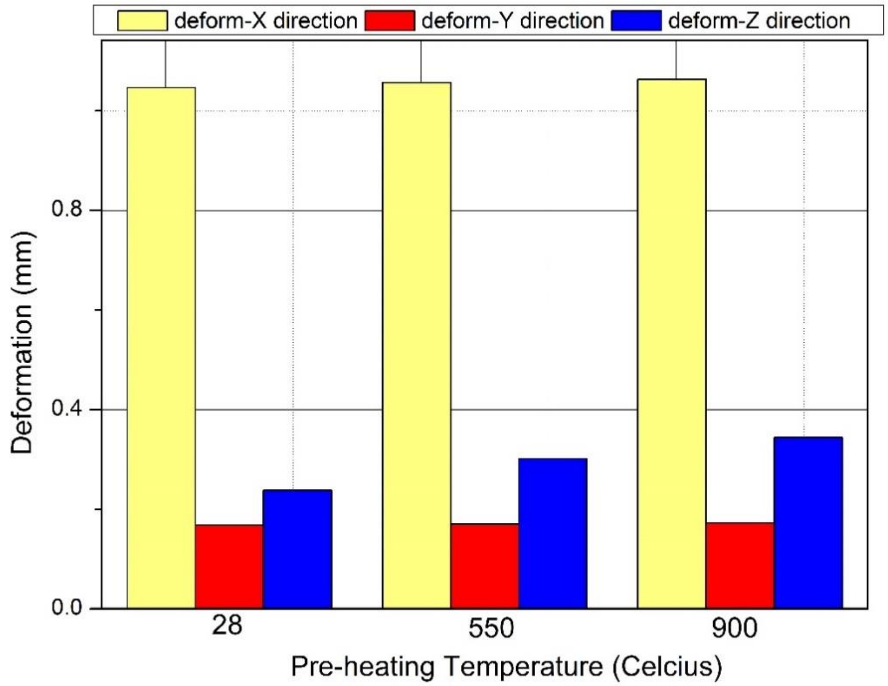

Figure 10. Graph of deformation in 3 different direction

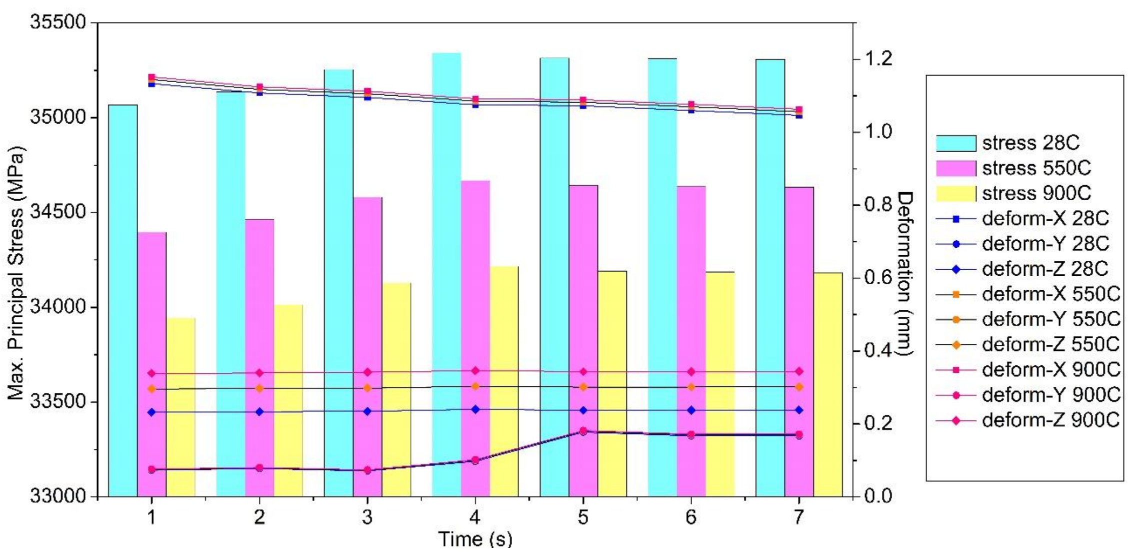

Figure 11. Graph of principal stress and deformation against the HPF process duration.

CONCLUSION

In this paper, springback occurrence within hot press forming (HPF) process was studied comprehensively by conducting both experimental works and numerical simulation analysis. In HPF experiment, the results presented concluded that high pre-heating temperature (900°C) may reduce springback failure on sheet metal effectively and the desired geometry of part could be acquired without compromise. For 900°C workpiece, the left and right bending angle were 65° and 58°; for 550°C, recorded 64° and 62°; and for 28°C, with 63° and 68°. Bending angle of 28°C workpiece increased by 6.51%, in comparison to 900°C. For simulation study, ANSYS Workbench Transient Structural was applied to study the stress distribution along the workpiece and deformation with different orientation. The simulation results shown 900°C temperature have the lowest maximum principal stress value, recorded 34216 MPa; whereas 28°C recorded the highest maximum principal stress value, recorded 35341 MPa, which increased by 3.29% when compared to 900°C workpiece. This justify that high pre-heating temperature will cause the blank to become ductile and possess high formability. In term of deformation, 900°C workpiece also shows the highest magnitude in term of various orientations (X-direction=1.063mm, Y-direction=0.172mm and Z-direction=0.344mm), which tally with previous results. Throughout the study, it can be conclude that in hot press forming, the pre-heating temperature was one of the major process parameter that may strongly affect the occurrence of springback phenomena on the structural component. Data and results obtained within this study were very beneficial to be adopted as reference and auxiliary for future research.

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