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JOHNSON COOK CONSTITUTIVE MODELING FOR AUSTENITE METAL IN HOT FORMING PROCESS

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Abstract

Numerical computations have helped process engineers in designing the stamping process with minimal process defects. The constitutive modelling for hot stamping represents a complex relationship between stress, strain, strain rate and process temperature. The sheet thickness is 1.5 mm were prepared according to the ASTM standard. The flow curve properties of NPH-1500 sheet were investigated by conducting uniaxial tension tests with temperature from 600oC to 800oC and subjected to strain rate of 0.1/s,1/s and 10/s. The flow curves for the respective experiment runs were investigated and modelled with Johnson Cook constitutive modelling where the important metal parameters were derived. Based on the results, the error of the metal parameters values from experimental works and commercial database was found to be less than 5%.

Keywords: Johnson cook constitutive model; flow curve; embedded material model; material stress, hot stamping

Abstrak

Pengiraan kaedah berangka telah membantu jurutera proses di dalam rekabentuk bagi proses pembentukan dengan kecacatan proses yang minimum. Pemodelan bahan bagi proses pembentukan panas *(hot stamping)* adalah diwakili oleh hubungan kompleks diantara tegasan, terikan, kadar terikan dan suhu proses. Ketebalan spesimen ialah 1.5 mm dan disediakan mengikut piawaian ASTM. Ciri-ciri lengkuk tegasan-terikan bagi bahan NPH-1500 telah disiasat dengan menjalankan ujian ketegangan dengan suhu dari 600°C ke 800°C dengan kadar terikan pada 0.1/ s, 1/ s dan 10/ s. Penyiasatan ciri-ciri lengkuk tegasan-terikan disiasat dan dimodelkan dengan model bahan Johnson Cook di mana parameter logam utama telah diperolehi. Berdasarkan analisis, nilai ralat bagi parameter logam nilai dari eksperimen dan data rujukan perisian adalah kurang daripada 5%.

Kata kunci: Model juzuk Johnson cook, lengkuk aliran, model bahan terbenam, tegasan bahan, proses pembentukan panas

1.0 INTRODUCTION

Numerical computation is an essential tool for engineers to produce defect-free stamped parts at the early design stage. Hot stamping is an advanced process used to manufacture high-strength structural parts. The engineers conduct virtual experiments using numerical computation to predict the defects and improve the process without any physical prototyping parts and stamping tools. The accuracy of the numerical computation relies heavily on the Finite Element modelling. The finite element modelling serves as the computer computation of constitutive modelling for specific behaviour such as the flow curve behaviour, thermal behaviour, material model and forming limit curve [1].

Constitutive equations are the integral functions of factors that represent the material flow behaviours. In hot stamping, constitutive equation describes the complex relationship of thermodynamic parameters, material parameters and structural data parameters. Therefore, the finite-element modelling for hot forming is a complex interaction between the thermal field, material field and structural field. The final part's hardness and mechanical properties depend on the microstructure formation and distribution that depend on the temperature history and mechanical deformation control [2][3]. The finite-element modelling of the material flow behaviour is influenced by factors such as strain, strain rate and process temperature, chemical composition and microstructure.

The objective of this paper is to validate the set-up of a testing facilities for the uni-axial tensile test for high strain rate and high temperature for Hot forming process. The statistical error is computed for stress strain behaviours for commercial data against experimental data for all experimental set-up. The experimental stress-strain data at elevated temperatures with various strain rates were obtained from the tensile test experiment. While, the commercial database are obtained from available material database from commercial simulation software. Subsequently, we derived the Johnson Cook material constant from both the experimental data and commercial data for hot forming simulation works.

2.0 CONSTITUTIVE LAW OF HIGH STRENGTH STEEL

The elementary form of the model readily adaptable to most FE codes for modelling the constitutive model for large strain, high strain rates and high temperature is given in general form,

$$f(\sigma) = (\epsilon, \dot{\epsilon}, T) \qquad (1)$$

Where, σ, is the normal stress acting on a plane; ϵ represents the effective dimensionless strain, $\dot{\epsilon}$ is the normalized strain rate and T is the normalized temperature.

The Johnson–Cook model is an equation for high temperature flow stress model, σ, that represent the flow stress as a distinctive function of strain, strain rate, temperature that describe the relationship of the loading path of material [4].

$$\sigma = [A+B\,\varepsilon^{n}][1+C\ln\dot{\varepsilon}]\left[1-\left(\frac{T-T_0}{T_f-T_0}\right)^{m}\right] \qquad (2)$$

Where $\dot{\epsilon}$ is the reference strain rate; T_0 is the initial temperature and T_f is the melting temperature. While A, B, C, n and m are material constants.

As Johnson Cook equation is generally computed for high strength material for critical applications such as Defence and Aerospace. Several research works have derived the value of constants for Johnson Cook [5][6][7]. In the work by[8], the five-parameter Johnson Cook is obtained from Quasi-Static Tensile for three different material grade have produced good qualitative and quantitative results for armour Perforation tests. The numerical simulation is also used to validate the Johnson Cook constants obtained from experimental works. The work by [9] has simulated the boron tensile test by explicit finite element code for spring back verification work during stamping process.

3.0 MATERIAL AND EXPERIMENT

The commercial code name for Boron steel is NPH-1500 with Aluminium coating (AISI 5120). The metallurgical composition data are obtained from the spectrum analytical instrument and contain major alloying elements such as Mn 1.21 ppm and Boron 24 ppm. The basic mechanical properties for NPH-1500 are the Yield strength approximately from 471 – 499 N/mm^2, also Tensile strength approximately 634 – 647 N/mm^2 with 21% in elongation.

The tensile test was performed on the universal tensile machine and equipped with hot gas compartment for uniform temperature distribution. The temperature of specimens is detected with the radiotic thermal camera. The hot gas compartment is covered by bricks for uniform heat environment. The machines specification for the hot tensile is tabulated in Table 1.

Table 1 Equipment for hot tensile test experimental works

Equipment	Features	Specifications
Tensile Specification	Machine Name	Victor, Model VEW 2302
	Maximum Test Load	100kN
	Measuring specimen deformation	Extensometer with 50mm gauge length and 25 mm deformation
	Clamping System	Hydraulic Grippers
Hot Gas Compartment	Compartment	Bricks Covered with Hot gas and Nozzles
Temperature measurement	Heat Detection range	0°C to 1200°C
	Thermal sensitivity	80 mK

The samples were machined according to the ASTM E8/E8M Standard Test Methods for Tension Testing of Metallic Materials outline to the proper dimensions and profile for specimen [10]. The specimen is only machined according to parallel direction of rolling direction. The anisotropy behaviours are almost disappeared after the specimen is heated at high austenizing temperature [11].

4.0 RESULTS AND DISCUSSION

The tensile specimen, NPH-1500 specimen with 1.5mm of thickness was subjected to the designated strain rate (0.1/s, 1.0/s, 10/s) and heated by the constant flow of hot gas to obtain stable designated temperatures from 600 °C to 800 °C. There are nine (9) setups for all strain rates and temperatures in combination. The temperature of the compartment is detected using a thermal heat camera with high temperature sensitivity.

The engineering stress strain for all experiments is shown in figure 1. Normally, the engineering stress strain graph is used because it gives the value of Young's Modulus (E), Yield Strength(Y), Tensile Strength and percentage of Elongation (at Failure) directly from the stress strain curve.

The deformation process such as the forming process requires the non-linear modelling for the material flow curve. The engineering stress strain is not able to represent such modelling because it is based on original specimen geometry. After the yielding point is surpassed, the stress required to produce continuous deformation is also increased. The stress is concentrated on the smaller specimen geometry and its continuously increases until it reaches the fracture point.

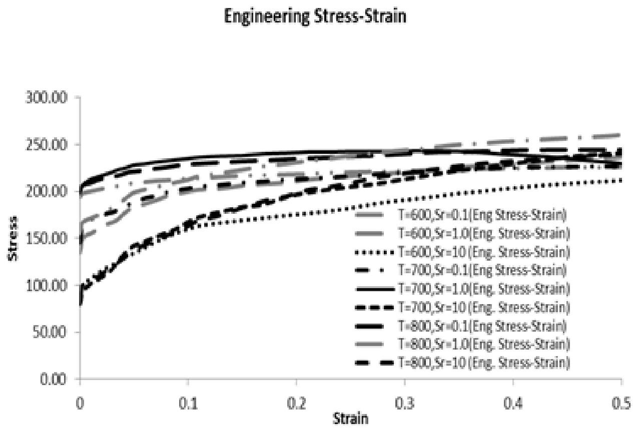

Figure 1 Engineering Stress Strain for 600°C, 700°C and 800°C for strain rate 0.1/s, 1/s and 10/s

Figure 2 shows the true stress strain curve at temperatures of 600°C, 700°C and 800°C. Generally, the material strength decreases as the temperature increases. The flow curves indicate that temperature has a significant influence in forming behaviour of the NPH-1500 steel grade.

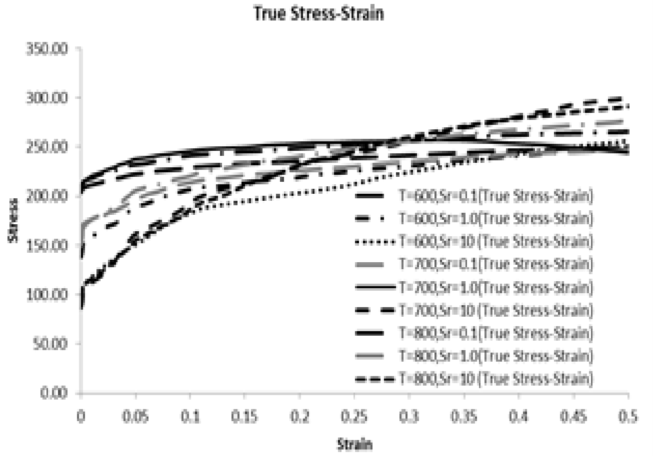

Figure 2 True Stress Strain for 600°C, 700°C and 800°C for strain rate 0.1/s, 1/s and 10/s

Figure 2 has indicated the significance of the high temperature and large strain on deformation behaviours for the NPH 1500 material. The behaviours must be modelled with FE material modelling i.e Johnson Cook. The key parameters of Johnson Cook are derived by fitting the true stress-strain data to Johnson Cook equation [12]. The selected merit function to solve the parameters is expressed mathematically as:

$$\varkappa^2 = \sum_{i=1}^{N} \left(\frac{Y_i - f(X_i,\theta)}{\omega_i}\right)^2 = \sum_{i=1}^{N} \left(\frac{r_i}{\omega_i}\right)^2 \tag{3}$$

where $\varkappa^2$ is the weighted sum of the squares of the residual r_i and function of vector θ and number of data point, N for X_iY_i. The derived value from the merit function are expressed in table 2.

Table 2 Derived values for johnson cook parameters

Temperature	Strain Rate	A	B	C	m	n
700°C	0.1	148.29	132.63	0.31	0.01	10
	1	197.13	70.32	0.20	0.01	10
	10	77.00	302.56	0.45	0.01	10

A detailed discussion of the differences between the commercial and experimental true stress for the one-dimensional test is being discussed by [13]. In this investigation, we summarized the commercial and experimental errors as the following:

$$Error\ of\ \sigma = \left(\frac{\sigma_{commercial} - \sigma_{Exp.}}{\sigma_{Exp.}}\right) x\ 100 \tag{4}$$

For discussion purpose, we calculate the errors for flow stress for temperature at 700°C for 0.1/s strain rate. The parameter values from Table 1 is utilized in the Johnson Cook equation. By using statistical functions, the errors of each flow stress for each true strain value is calculated and summarized in table 3.

Table 3 Errors statitical value for commercial database and experimental values.

Temperature (°C)	Strain Rate (/s)	Error	$\sigma_{commercial}$	$\sigma_{Exp.}$
700	0.1	Max.	2.83	
		Min.	-3.03	
		Mean	0.02	
		Median	0.02	
		Std. Dev.	1.48	

5.0 CONCLUSION

In this study, we have successfully set-up the testing facilities for the Tensile Test for high strain rate and high temperature for Hot forming process. The experimental data from the new testing facilities were validated against the calculated and commercial values. The error from both values was only deviated at a maximum 2.83% for temperature at 700°C with 0.1/s strain rate. We derived the values for Johnson Cook parameters from the experimental data by using the merit function of the least square methods. Based on the results, the error of the metal parameters values from experimental works and commercial database was found to be less than 5%. The derived parameters will be used as an input in the FE modelling for structural parts. The simulation works for such parts have assisted engineers to detect the potential defects in parts at the early design stage[14].

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