EFFECT OF TEMPERATURE ON MATERIAL BEHAVIOUR IN THE TENSILE TEST

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Abstract

In modern engineering, the possibility of predicting the behaviour of processed material by means of numerical simulation is increasingly used. Knowledge of this issue is important to ensure the stability of the pressing process. Achieving higher process stability leads to a reduction in the number of correction loops for forming tool optimisation, and lower production rejects, and time and financial savings in tool and die shops. However, with respect to increasing productivity, there is instability in the pressing process, which may be related to the material's behaviour when the deformation rate changes. There is a change in tool temperature due to friction between the tool and the material and heating of the material due to deformation. Therefore, it would be interesting to see whether the mechanical properties of the material change with temperature. The thermal effects in the cold-forming process should be implemented in the numerical simulations. This work aims to carry out a heating design that will allow heating to temperatures corresponding to those of the pressing process. The specimen should be visible for the possibility of deformation analysis, e.g. by the ARAMIS system, which works on the principle of digital image correlation. The functionality of the designed device will be tested in tensile tests. Different temperatures from ambient to 160 °C will be measured to cover the continuous heating process in real forming.

Keywords: Tensile test, Cold forming, Heating methods, Forming simulation, Mechanical properties

1. INTRODUCTION

The deformation curves for different strain rates can be measured by varying the test speed. The measurement results of these deformation curves for a specific material are used to simulate the forming process. For the simulation to work properly, the mechanical properties and behaviour of the material must be accurately defined.

For example, during the pressing of sheet metal, heat is generated by the individual strokes of the pressing tool, which causes it to heat up from ambient temperature up to 120 °C gradually. Suppose this temperature change is not considered in the simulation. In that case, the accuracy of predicting the formed material's behaviour may be reduced, and the dimensional accuracy of the pressed product may deteriorate.

The heating device currently used for this measurement in the mechanical testing laboratory can be reliably heated up only to a temperature of 300 °C and above. The sample must be sealed in this furnace throughout the test and can only be viewed through a narrow window.

2. DESIGN OF THE DEVICE

In this section, I will first describe the design of the experiment. Based on the solution of the possible heating methods and temperature measurements, I will select the most suitable method and choose the most suitable variant to be implemented. With this equipment, I will verify the proposed solution by tensile testing on selected samples at elevated temperatures.

2.1 Design of the experiment

The experiment aims to design an elevated temperature tensile test device to simulate the temperatures reached during sheet metal forming in a press tool and verify the material behaviour at this temperature change.

Tensile tests will be conducted in the temperature range from 80 °C to 160 °C. It is assumed that the temperature of the sample will be controlled during the tensile test so that its change during the test is minimal. The sample must be heated as a whole and uniformly as possible. The tests will be carried out on LabTest 5.100SP1, and samples from DX57 material will be used.

2.2 Sample heating methods

In this section, I will list the methods that can be used for heating solid-state materials in laboratory conditions and point out their advantages and disadvantages. From these methods, I will then select the one that is most suitable in terms of the design of the heating device for the tensile test.

Table 1 Pros and cons of usable heating methods [1-11]

Heating method	**Advantages**	**Disadvantages**
Forced convection	Simple, cheap, safe device	High heat loss, low efficiency, limited temperature control and stability
Electric induction	Fast and uniform heating, control by changing the current and voltage characteristics of the coil, coil does not heat up, heat is generated only in the material being heated, high efficiency, automation	For materials with high electrical and thermal conductivity, heating from surface to core, risk of electric shock, expensive
Infrared radiation	Instantaneous heating, possible even in vacuum, material does not need to be electrically conductive, inexpensive, low operating costs, temperature control by changing wavelength	High temperature radiator, fire hazard, radiator must be suitably located, temperature sensors may be affected by infrared radiation
Direct electrical resistance	High efficiency, uniform heating, control by changing the electric current, maximum heating temperature according to the material to be heated	Conductive material with high electrical resistance required, permanent connection to a power source required, risk of electric shock, only non-contact temperature measurement
Indirect electrical resistance	Efficiency increases with increasing temperature, shape of heating elements can be adjusted for higher efficiency, easy temperature control, material does not have to be electrically conductive	Slow heat transfer by flow with non-contact heater, radiant only from higher temperatures, material must be well thermally conductive, heating unevenly from surface to core

2.3 Temperature measurement methods

Not every method of temperature measurement is suitable for the described experiment. It is necessary to consider how the sensor can be placed on the sample for contact measurements and the instrument's accuracy.

A suitable instrument for the experiment is a sensor that allows temperatures in the range of 80 to 160 °C to be measured with good accuracy and can be used in combination with a tensile testing machine. In the case of a touch measurement, it is necessary to consider clamping it to the sample. In the case of non-contact measurement, the influence of external factors on the instrument's accuracy must be considered.

Key characteristics of this experiment include the range of applicable temperatures, the accuracy and the cost of the instrument. The following table gives indicative values for these characteristics for each type of usable instrument.

Table 2 Usable methods of temperature measurement [12-15]

Temperature measurement method	**Temperature range**	**Measurement inaccuracy**	**Price range [CZK]**
Metal resistance thermometer	-200 – 850 °C	0,15 – 3,3 °C	1 000 – 15 000
Thermocouple	- 40 – 1 600 °C	1,0 – 2,5 °C	1 000 – 15 000
Infrared pyrometer	- 50 – 975 °C	1,0 – 1,5 °C	5 000 - 50 000
Infrared camera	-20 – 900 °C	0,5 – 2,0 °C	15 000 – 200 000

2.4 Designed device

I will use indirect electrical resistance to heat the sample. This is implemented by a heating coil placed inside an aluminium tablet. This aluminium tablet is in contact with the sample during the measurement. The temperature measurement is carried out using a thermocouple which is placed by a step clamp on the sample's surface as close as possible to the aluminium tablet. These components are connected to a PLC, which can be set to a specific measurement temperature. During the entire test process, the heating element is regulated by a PLC so that the temperature does not drop or rise rapidly. The wiring of the components and the location of the heating device are shown in the following figure.

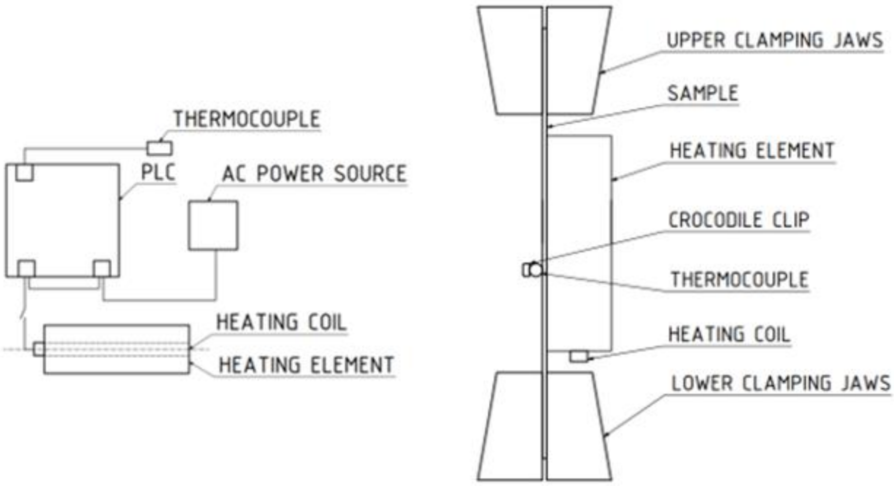

Figure 1 Wiring scheme (left) and clamping scheme (right)

2.5 Experimental measurement

First, I will define here the expected properties of the DX57 material. I will perform tensile tests for the selected temperatures with the testing parameters I have chosen according to the standard. The selected tensile test temperatures are 80, 120 and 160 °C. Furthermore, for comparison, I will perform a tensile test at an ambient temperature of 20 °C while maintaining the same clamping method for the aluminium tablet. These tests will determine if and how significantly the material properties of the sheet forming process vary with temperature.

Table 3 Testing parameters

Test standard	Tensile test of metal - DIN EN ISO 6892-1
Force sensor	100 kN
Test speeds	V0 = 2 mm/min; V1 = 2 mm/min; V2 = 10 mm/min
Switching points	F0 = 100 N; U12 = 3 %
Test termination criteria	Force = 70 000 N; dF = 75 %

Table 4 Tensile test results

Temperature [°C]	$R_{p0,2}$ **[N/mm²]**	R_m **[N/mm²]**	*A* **[%]**
20	155	298	41,5
80	138	234	24,9
120	132	225	22,8
160	137	219	22,9

As the testing temperature increases, the ultimate strength, yield strength and ductility gradually decrease.

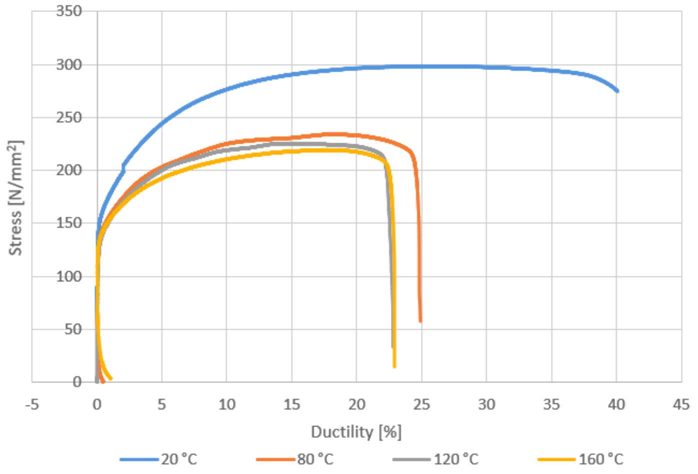

Figure 1 Wiring scheme (left) and clamping scheme (right)

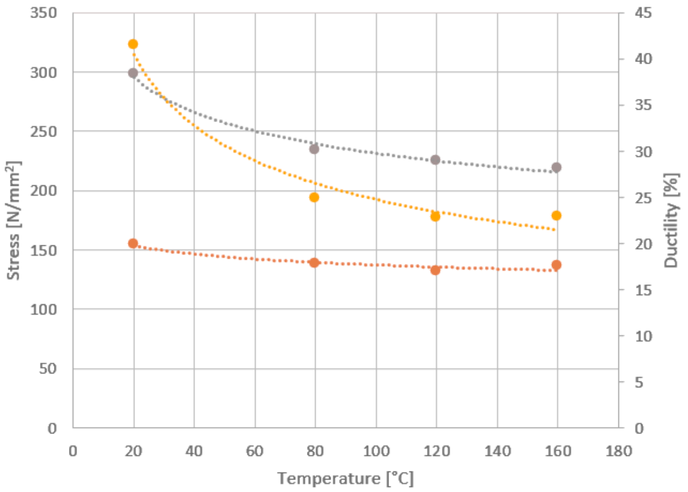

Figure 2 Graphical representation of mechanical properties with change of temperature

In the graphs, it can be seen what the specific tensile test runs were and how the mechanical properties vary with temperature. The difference in the maximum tensile strength of the sample at normal temperature compared to the heated samples can also be seen.

As the temperature increases in the range of 20 — 160 °C, the strength and ductility of the material drop significantly. The general assumption is that changes in mechanical properties should not be significant at these temperatures. This assumption has not been confirmed by these initial measurement results and it is therefore necessary to look further into the reasons that might have caused these differences in mechanical properties.

3. DISCUSSION

The measured values show that mechanical properties can vary with temperature. I will describe the possible influence of temperature and give recommendations that should facilitate future measurements that can be performed using the described method of heating the samples for tensile testing.

3.1 Effect of temperature on the mechanical properties of the material

An experiment was carried out which showed that even a relatively small change in temperature during cold forming can critically affect the mechanical properties of the material. This must be put in the context that most tensile testing of cold-formed materials is conducted at ambient temperature. This finding directly contradicts the well-established assertion that for most cold forming operations, it is unnecessary to consider the effect of temperature. The equipment proposed in this work is suitable for verifying the deformation behavior of materials and mechanical properties as a function of temperature.

4. CONCLUSION

This work aimed to design a device for heating the sample for tensile testing, which can be used in the future to better describe the material behaviour during forming at elevated temperatures up to 160 °C.

The motivation was to analyze the effect of temperature on the material behaviour corresponding to the conditions in the press tool. Typically, tensile testing is performed at ambient temperature and the measured material characteristics are subsequently used, for example, to verify mechanical properties, to determine plastic behaviour within the forming process, or to describe material behaviour for process simulation. Differences between simulation results and actual cold forming have already been observed in practice.

Using the designed device, I performed tensile tests on the material at 80, 120 and 160 °C temperatures. I chose the temperatures with consideration of the temperature field analysis performed in the press tool.

In the experiments, the elevated temperatures were found to significantly affect the material properties obtained, with these properties being significantly different from expectations. The material data sheet shows the mechanical properties of grade DX57, which were determined at 20 °C. Comparing these with the measured results, I found that with increasing temperature, yield strength, ultimate strength, and ductility decreased.

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