

APPLICATION OF THERMOGRAPHY IN DETERMINING THE PROPORTIONALITY LIMIT

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Abstract: The determination of the proportionality limit was performed to determine the beginning of the plastic flow of steel during cold deformation as accurately as possible. Measurements were performed by static tensile tests using an extensometer and a thermographic camera. The research has shown that with thermography is possible to determine the beginning of the plastic flow of material with high accuracy.

1 INTRODUCTION

Today, the accurate determination of the beginning of the metallic materials plastic flow has great importance during the metal forming with various metal forming technologies [1]. The static tensile testing, using an external extensometer to determine the proof strength, $R_{p0.2}$, is used as a standard method to determine the beginning of the plastic flow of metallic materials.

The additional opportunities appear with the development of technology and by using modern methods in the field of plastic deformation, such as thermography [2] and digital image correlation [3], for the determination of the plastic flow beginning of metallic materials [4]. It is often difficult to determine the beginning of plastic flow in metallic materials that do not have a pronounced transition from elastic to elastoplastic deformation [5].

Thermography has been proven as a suitable method for testing the deformation zone because of a change in the temperature of the metallic materials due to the plastic work during the plastic deformation [6,7]. Since phenomena such as the thermoelastic effect [4] and the appearance of inhomogeneous deformations, e.g. Lüders bands [8] occur at the beginning of the plastic flow, the thermographic method is becoming increasingly important. The thermographic method is often used to study the beginning of plastic flow of metallic materials [9,10].

This paper aims to research the possibility of the determination of the plastic flow beginning, i.e., the proportionality limit, of low-carbon steel during static tensile testing using the method of thermography.

2 EXPERIMENTAL WORK

The tests were performed on low-carbon steel samples from a hot-rolled sheet. The samples were taken in the rolling direction of the steel. The dimensions of the tested samples are original gauge length of 45 mm, original width of 20 mm and thickness of 3 mm. The chemical composition of the tested low-carbon steel is shown in Table 1.

Table 1 Chemical composition of low carbon steel (wt. %)

Element	C	Mn	Si	P	S	Al
Low carbon steel	0.13	0.77	0.18	0.010	0.019	0.020

Static tensile tests were performed on a WPM EU 40 mod testing machine with and without using an external extensometer. The tests were monitored by the thermal camera with continuous recording of the gauge length of test samples.

The test with an extensometer was carried out by placing an external extensometer on the test samples. An external extensometer was set up to determine the proof strength, $R_{p0.2}$. The computer stopped the testing machine to remove the extensometer when the proof strength was reached. Further elongation of the sample was measured with an internal extensometer, located inside the testing machine, until the test sample fracture.

The test without an external extensometer was performed in the same way as in the before-mentioned case. Still, in this case, the test samples were continuously stretched without stopping until the fracture of the test sample.

Simultaneous recording of test samples during stretching was performed with a VarioCAM®M82910 thermal camera manufactured by JENOPTIK. Black matt coating ColorMatic LECHSYS 29141, with an emissivity factor of 0.95, was used for thermographic tests. The temperature sensitivity of the thermal camera used for the tests is 80 mK.

3 RESULTS AND DISCUSSION

The force-elongation diagram shows the drop of force values immediately after reaching the proof strength of the test sample with an external extensometer, blue circle on Figure 1. A drop of force is the cause of the interruption of the

testing machine operation when reaching the proof strength, $R_{p0.2}$. After that, the operation of the testing machine switches from the removed external extensometer to the extensometer inside the testing machine.

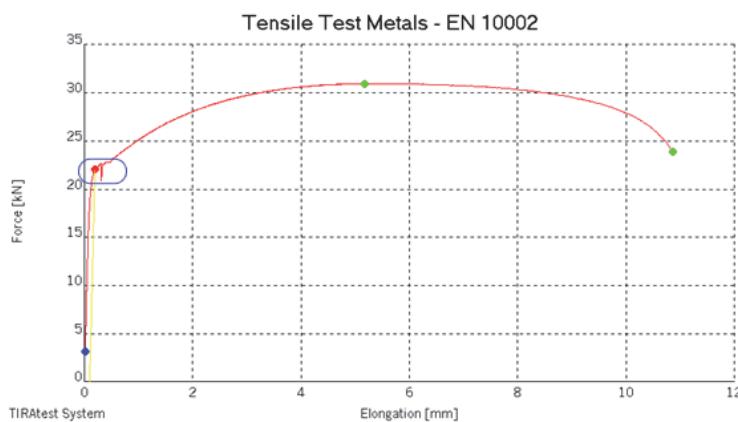


Figure 1. Force-elongation diagram of the sample with an external extensometer

Simultaneously with the static tensile testing with an extensometer, thermographic tests were performed to determine the beginning of the plastic flow. There were some specific issues with thermographic measurements of temperature changes. The first problem was stopping the testing machine operation by reaching the proof strength of low-carbon steel during measuring with an external extensometer and thermography. The testing machine has to be stopped because it was necessary to remove the external extensometer when the value of proof strength is reached. Since the beginning of the plastic deformation occurs before that, there is a deviation of the temperature values at the beginning of the plastic flow of the tested steel, Figure 2.

Figure 2 shows a flat part on the diagram of temperature changes over time, and it is impossible to determine the beginning of the plastic flow of low-carbon steel. The stagnation in the temperature changes in Figure 2 (part II) occurs since the deformation process was recorded by thermography in three parts (part I, part II and part III). The first part of the measurement by thermography refers to the area until the proof strength, $R_{p0.2}$, is reached (part I). The second part of the thermographic measurement refers to the flat line area on the diagram at the moment of stopping the testing machine and removing the external extensometer from the sample (part II) and the third part of the measurement refers to the area of further continuous temperature increase after restart of the testing machine until the test sample fracture (part III). Therefore, in the case of determining the beginning of the plastic flow by thermography during static tensile testing with an external extensometer, it is impossible to determine the accurate beginning of the plastic flow in the tested steel.

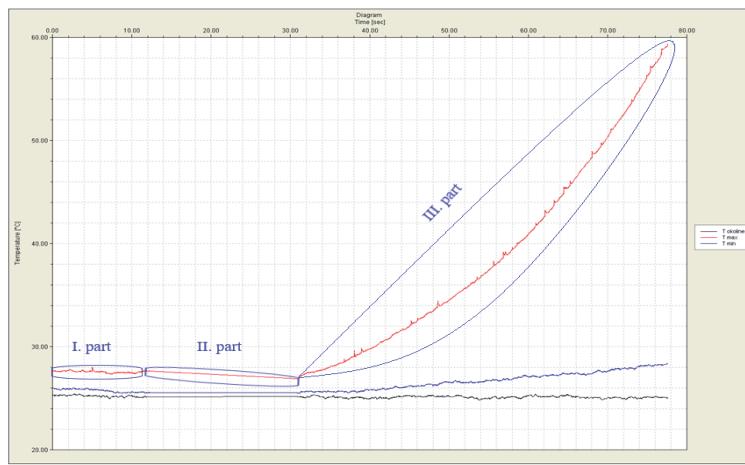


Figure 2. Diagram of temperature increase in the sample with an external extensometer

Determining the beginning of the plastic flow of steel by thermography during static tensile testing with an extensometer arises another problem because the extensometer covers a large part of the test sample surface, blue mark in Figure 3. There is interference and difficult measurement of test sample temperature distribution during the test. At this time part of the energy is reflected from the external extensometer to the thermal camera lens. The thermal camera lens with energy reflected from the external extensometer has a measurement error that is difficult to calculate. Figure 3 shows the thermogram with an external extensometer on the test sample. It can be seen that the extensometer largely covers the test sample surface and manifests in the form of a brown colour. The evidence that the external extensometer reflects energy is a line analysis (orange line) performed on the test sample in Figure 3. The various temperature distribution along the length of the test sample can be seen on the recorded thermogram. The brown area in Figure 3, corresponding to the

external extensometer on the test sample, clearly shows the temperature increase in that area on line analysis (blue circles in Figure 4) which makes it difficult to measure the temperature distribution and determine the beginning of steel plastic flow, Figure 4.



Figure 3. Thermogram of the test sample with an external extensometer

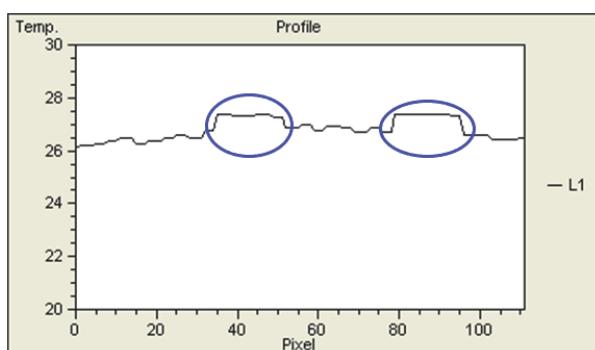


Figure 4. Line analysis of temperature distribution on test sample with an external extensometer

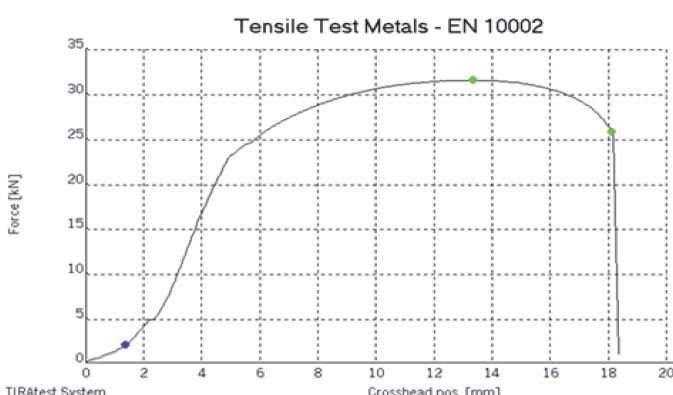


Figure 5. Force-elongation diagram of the sample without an external extensometer

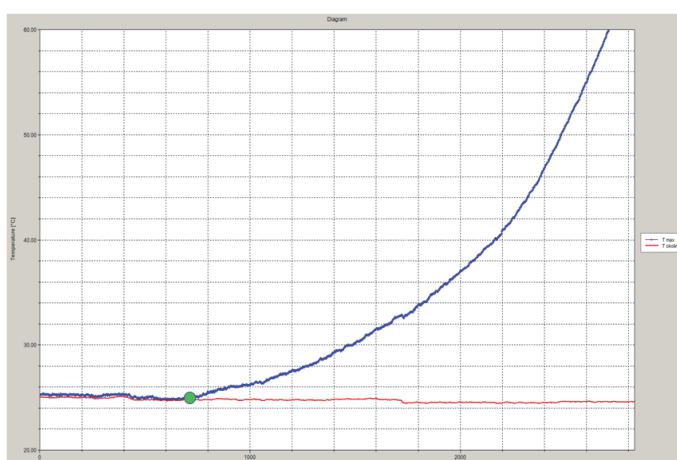


Figure 6. Diagram of temperature increase in the sample without an external extensometer

The test was also performed to determine the beginning of plastic flow by thermography during static tensile testing but without an external extensometer. Determination of the beginning of the plastic flow, on the test sample without an external extensometer, did not show a decrease in the force values after reaching the proof strength, Figure 5.

Since the testing machine was not stopped during the testing without using an external extensometer, it is possible to determine the moment of proportionality limit reaching at the beginning of the plastic flow of low-carbon steel from the diagram of temperature changes during deformation, Figure 6. The proportionality limit at the beginning of the plastic flow of steel in Figure 6 is manifested in the sudden temperature increase (green dot in Figure 6).

There was no problem of difficult measurement of temperature changes during determination at the beginning of the plastic flow of steel since it is possible to measure accurate amounts given a clean surface of the test sample without an external extensometer. Previous research on the beginning of the plastic flow of metals by thermography confirms that the first positive temperature change occurs at the beginning of the plastic flow of material [9].

4 CONCLUSION

The conducted research showed that using an external extensometer during static tensile testing causes great problems in determining the beginning of plastic flow by thermography. It was found that it is impossible to determine the accurate beginning of the plastic flow of steel by thermography during static tensile testing with an external extensometer. It has been shown that using an external extensometer, stopping the testing machine and removing the external extensometer from the test sample during the determination of the proportionality limit at the beginning of plastic flow by thermography makes it difficult to measure the temperature distribution of the test samples. The proportionality limit at the beginning of the plastic flow of low-carbon steel can be determined accurately by thermography during a static tensile test without an external extensometer.

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