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INFLUENCE OF TEMPERATURE AND STRUCTURE ON THE FORMABILITY OF STEELS FOR THE PRODUCTION OF SEAMLESS TUBES

WPŁYW TEMPERATURY I STRUKTURY NA ODKSZTAŁCALNOŚĆ STALI DO PRODUKCJI RUR BEZSZWOWYCH

The aim of the paper was to determine the temperature dependence of formability of investigated steels by uniaxial tensile fracture tests under thermomechanical conditions corresponding to punching (1340–1395 °C) and pilger rolling (800–1050 °C) in The Tube Mill TŘINECKÉ ŽELEZÁRNY a.s. The deformation behavior of N1 and 42CrMo4 steels was investigated. In both cases, the effect of the structure on formability was taken into account. In the case of high-temperature examination corresponding to the punching process, the tests were performed on samples taken from the area of the column crystals (i.e. closer to the outer surface of the continuously cast semi-finished product) and also from the area below the column crystals closer to the center. In the case of low-temperature tests corresponding to pilger rolling, the strength-plastic properties were evaluated from an area closer to the inner or closer to the outer surface of the roll after punching. Uniaxial tensile tests to the fracture were performed on the HDS-20 simulator.

Keywords: *seamless tubes, uniaxial tensile test, punching process, pilger rolling*

Celem pracy było określenie odkształcalności badanych stali w zależności od temperatury metodą badań pękania w jednoosiowym stanie naprężenia przy rozciąganiu w warunkach termomechanicznych odpowiadających dziurowaniu (1340–1395 °C) i walcowaniu pielgrzymowemu (800–1050 °C) w Walcowni Rur TŘINECKÉ ŽELEZÁRNY a.s. Zbadano odkształcalność stali N1 i 42CrMo4. W obu przypadkach uwzględniono wpływ struktury na odkształcalność. W przypadku badania wysokotemperaturowego odpowiadającego procesowi dziurowania, badania przeprowadzono na próbkach pobranych z obszaru kryształów kolumnowych (tj. bliżej zewnętrznej powierzchni półwyrobu odlewanego w sposób ciągły), a także z obszaru poniżej kryształów kolumnowych bliżej środka. W przypadku badań niskotemperaturowych odpowiadających walcowaniu pielgrzymowemu właściwości wytrzymałościowo-plastyczne oceniano z obszaru bliższego wewnętrznej lub zewnętrznej powierzchni walca po dziurowaniu. Próby rozciągania jednoosiowego do zerwania przeprowadzono na symulatorze HDS-20.

Słowa kluczowe*: rury bezszwowe, jednoosiowa próba rozciągania, proces dziurowania, walcowanie pielgrzymowe*

1. INTRODUCTION

The main aim of the experiment was to determine the temperature dependence of the formability of the delivered steels by uniaxial tensile fracture tests under thermomechanical conditions corresponding to the phases of punching and pilgrim rolling in the tube mill of Třinecké železáren a.s. The Big Mannesmann rolling line produces hot-formed seamless steel tubes by pilger rolling with an outer diameter from 168.3 mm to 406.4 mm and a wall thickness of 6.3 mm to 63.5 mm. The wall thickness ranges are limited by the manufactured diameter. Pipes are produced here from class 11–17 steel (carbon, stainless, low and medium alloy steels). The input material is mainly round ingots delivered from Třinecké železáren, then exceptionally ingots or billets.

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The heating before forming takes place in a carousel furnace, where the input material is heated according to the relevant heating group to the forming temperature. Forming temperatures and heating times are determined according to quality groups into which the input material is divided according to chemical composition. After exiting the carousel furnace, the blooms are centered on a punching device to optimize the start of the punching process, to a depth of approx. 30 mm. The billet is subsequently punched on a punching machine. After punching the material, and thus creating a hollow billet, this billet goes to the pilger mill. In front of the pilger mill itself, a pilger mandrel is inserted into the hollow billet, which ensures the exact inner diameter of the rolled pipe. With this mandrel, the billet is clamped into the feeding device of the pilger mill. Pilger rolling is essentially continuous longitudinal rolling, where the rolls are not in contact with the material during the entire revolution [1-4].

2. EXPERIMENT DESCRIPTION

The deformation behavior of steels N1 (marked with N) and 42CrMo4 (marked with C) was investigated. Cuttings for the production of samples were always taken from different locations of the initial semi-finished products.

In continuously cast semi-finished products, due to the high intensity of cooling, the growth of columnar crystals occurs, which grow in the direction of heat removal. In the next step, the solidification turns into so-called free crystalline growth, when seeds begin to appear for the subsequent formation of an equiaxed structure, which no longer has a precisely defined growth direction. The transition between columnar and equiaxed structure is never abrupt, but gradual, i.e. there is a certain transition area [5, 6]. Samples for the temperature range of punching (i.e. 1340–1395 °C) were taken from the area of columnar crystals (marked with O), i.e. closer to the outer surface of the continuously cast semi-finished products, and further from the area below the border of columnar crystals closer to the center (marked with H).

Samples for the temperature range of pilger rolling (i.e. 800–1050°C) were taken from the area closer to the inner (marked with S) or closer to the outer surface of the billet after punching (marked with P).

Uniaxial tension fracture tests were carried out on the HDS-20 simulator, or his Gleeble 3800 multipurpose unit [7, 8]. The sample dimensions are shown in Figure 1. The stainless steel hot grips used ensured a resistance-heated (i.e. measured) sample length of 20 mm (Fig. 2). The resistance heating of the samples was at the rate of 10 °C·s^{-1} directly straight to the deformation temperature, where 300 s delay followed. The pull of the sample into the fracture was at a stroke rate of 80 mm·s^{-1}), which corresponds to a mean value of the deformation rate of about 4 s^{-1} (obviously affected by the total elongation of the specific sample).

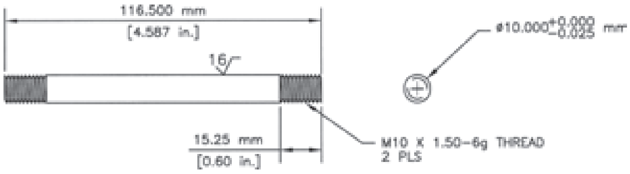

Fig. 1. Drawing of the specimen for uniaxial tension testing
Rys. 1. Ciągnienie próbki do jednoosiowej próby rozciągania

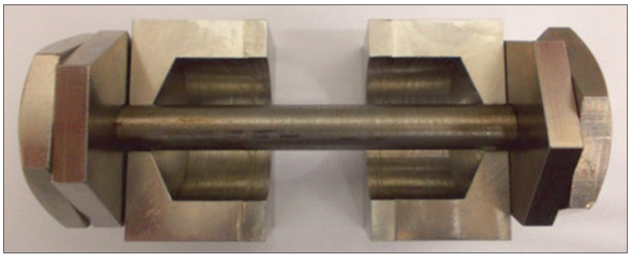

Fig. 2. The method of holding the sample in steel jaws
Rys. 2. Metoda wytrzymywania próbki w stalowych szczękach

From the data measured during tensile tests, the maximum force values F_{max} (kN) can be determined and these can then be used, together with the initial cross-section of the tested bars S_0 (mm), to calculate the ultimate tensile strength R_{mT} (MPa) of the material under investigation when hot:

$$R_{mT} = \frac{F_{max} \cdot 1000}{S_0} \quad (1)$$

In addition, from the values of the elongation to fracture of the tested bars, the hot ductility of the examined metal materials A_T (%) can be determined:

$$A_T = \frac{\Delta L}{L_0} \cdot 100 \quad (2)$$

where:
- ΔL – the elongation till fracture (mm)
- L_0 – the initial measured length, which in the case of stainless steel jaws is equal to 20 mm (of course, in the case of a total length of the test bar of 116.5 mm).

Contraction (%) is the maximum change in the cross-section after the test bar breaks and is compared to the original value of the cross-section. We calculate the contraction according to equation (3)

$$Z_T = \frac{S_0 - S_1}{S_0} \cdot 100 \quad (3)$$

where:
- S_0 – the original cross-sectional area before the test (mm)
- S_1 – the smallest cross-sectional area after the load test (mm).

The value S_1 is based on the size of the smallest diameter of the broken sample. This diameter was determined in the neck area with a digital caliper (measured always in 2 axes and averaged). Such a simple determination of contraction is burdened with a greater error than the determination of ductility.

In the following figures 3–6, graphs with curves of the measured force depending on the elongation are

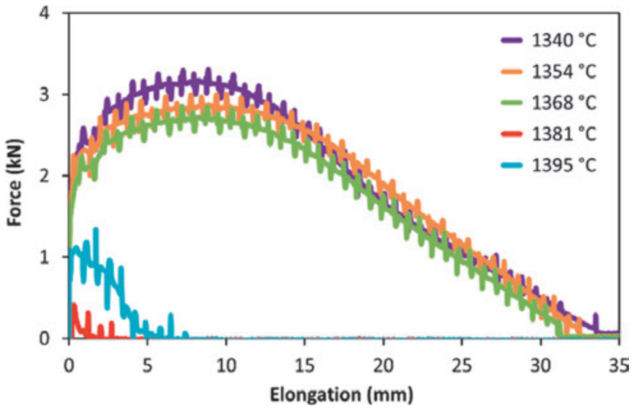

Fig. 3. Tensile test results – sample NO (steel N1, the area of columnar crystals)

Rys. 3. Wyniki próby rozciągania – próbka NO (stal N1, obszar kryształów kolumnowych)

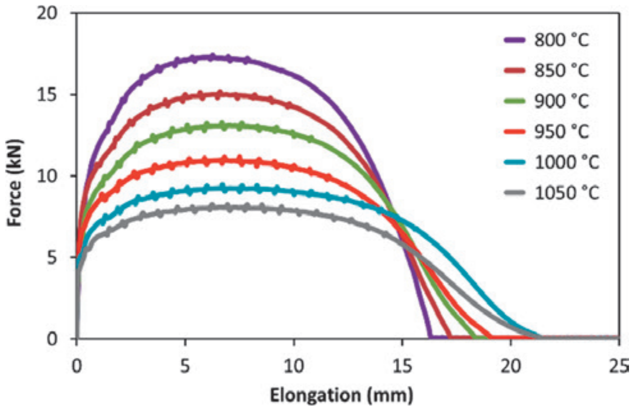

Fig. 4. Tensile test results – sample NP (steel N1, closer to the outer surface of the billet after punching)

Rys. 4. Wyniki próby rozciągania – próbka NP (stal N1, bliżej powierzchni zewnętrznej kęsa po dziurowaniu)

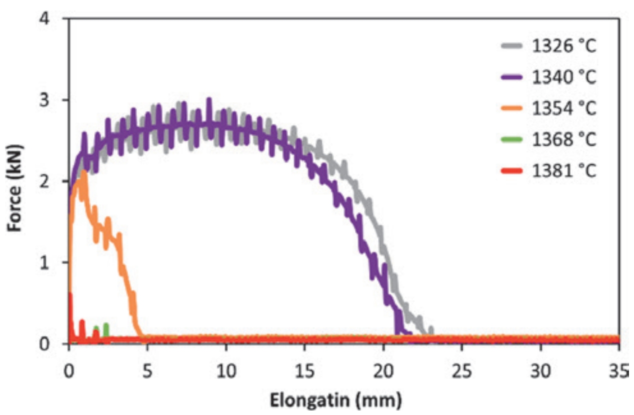

Fig. 5. Tensile test results – sample CH (steel 42CrMo4, from the area below the column crystals closer to the center)

Rys. 5. Wyniki próby rozciągania – próbka CH (stal 42CrMo4, z obszaru poniżej kryształów kolumnowych bliżej środka)

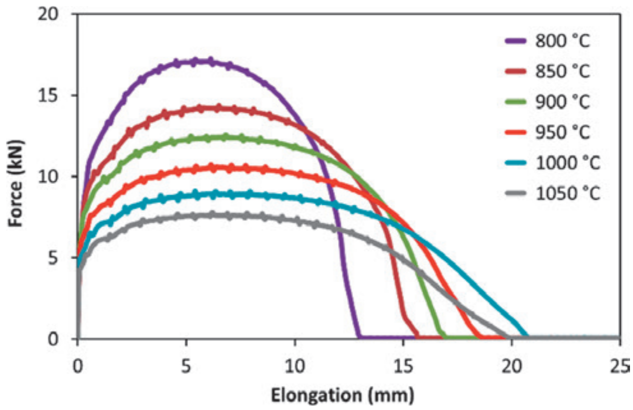

Fig. 6. Tensile test results – sample CS (steel 42CrMo4, from the area closer to the center)

Rys. 6. Wyniki próby rozciągania – próbka CS (stal 42CrMo4, z obszaru bliżej środka)

shown for the selected material-structural variants. During high-temperature testing of 42CrMo4 (C) steel, it became clear that it was unnecessary to perform tests at a temperature of 1395 °C, because even lower temperatures meant a sharp drop in plastic properties and almost zero ductility. Therefore, this steel was examined at a lower temperature, namely 1326 °C.

3. DISCUSSION OF RESULTS

The strength of all 4 material variants is practically the same in the temperature range of pilger rolling, in the high-temperature range corresponding to punching, its values are of course influenced by the amount of deformation to fracture – see Fig. 7–8.

As is clear from Fig. 9 to 12, the formability of individual material variants is very similar in the temperature range corresponding to pilger rolling, with a slightly upward trend. To some extent, the ductility of 42CrMo4 steel deviates in the area closer to the

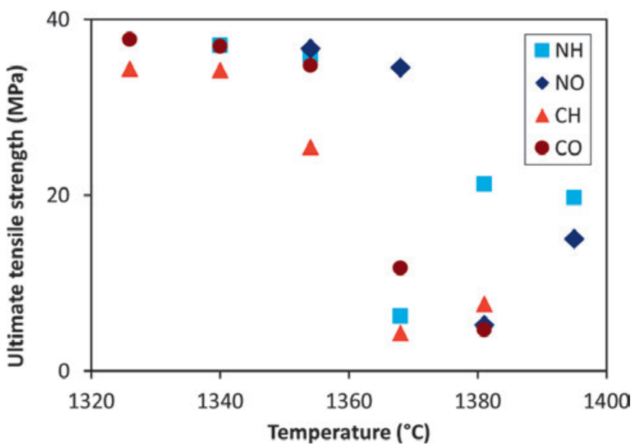

Fig. 7. Comparison of temperature dependences of strength for individual material variants (punching)

Rys. 7. Porównanie zależności temperatury od siły dla poszczególnych wariantów materiału (dziurowanie)

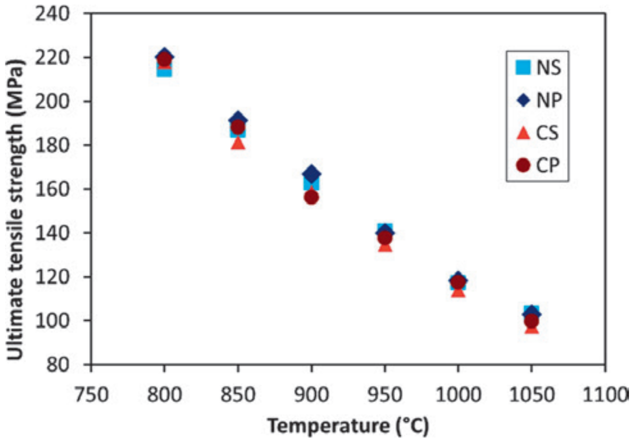

Fig. 8. Comparison of temperature dependences of strength for individual material variants (pilger rolling)

Rys. 8. Porównanie zależności temperatury od siły dla poszczególnych wariantów materiału (walcowanie pielgrzymowe)

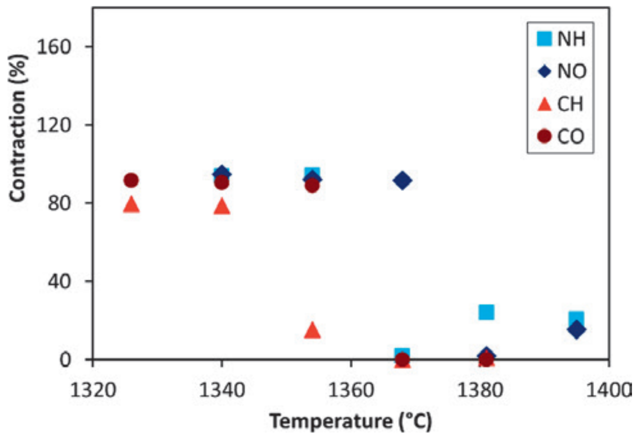

Fig. 11. Comparison of temperature dependences of contraction for individual material variants (punching)

Rys. 11. Porównanie zależności temperatury od ściskania dla poszczególnych wariantów materiału (dziurowanie)

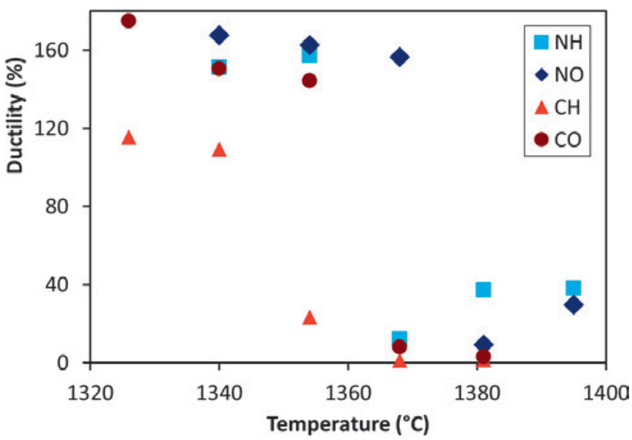

Fig. 9. Comparison of temperature dependences of ductility for individual material variants (punching)

Rys. 9. Porównanie zależności temperatury od ciągliwosci dla poszczególnych wariantów materiału (dziurowanie)

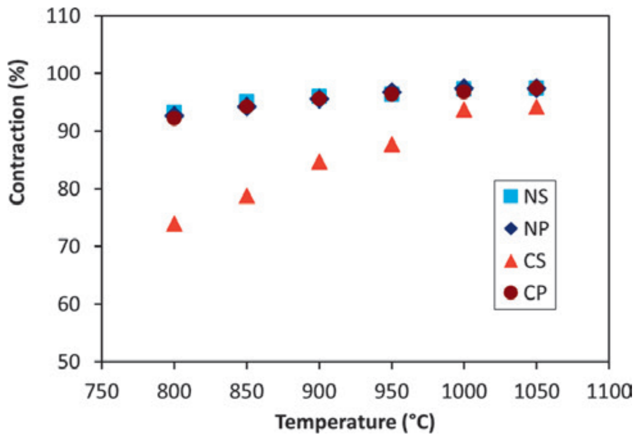

Fig. 12. Comparison of temperature dependences of contraction for individual material variants (pilger rolling)

Rys. 12. Porównanie zależności temperatury od ściskania dla poszczególnych wariantów materiału (walcowanie pielgrzymowe)

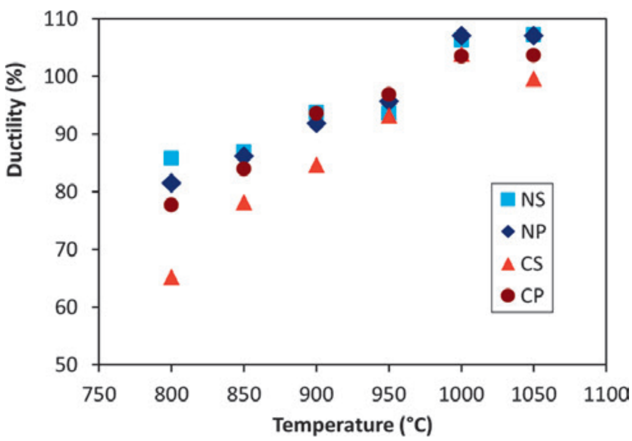

Fig. 10. Comparison of temperature dependences of ductility for individual material variants (pilger rolling)

Rys. 10. Porównanie zależności temperatury od ciągliwości dla poszczególnych wariantów materiału (walcowanie pielgrzymowe)

center, when it acquires slightly lower values, especially at the lowest temperatures. In any case, from the results obtained, the region of 1000–1050 °C appears to be the most favorable in terms of low-temperature formability, and it does not seem that a further increase in the pilger rolling temperature would lead to an improvement in the plastic properties of both investigated steels; however, this would need to be confirmed by further tests.

4. CONCLUSIONS

The experimental data from the high-temperature region, corresponding to the punching process, show a much low corelation, which is probably due to the heterogeneity of the initial casting structure. Under these conditions, N1 steel is more ductile than 42CrMo4 steel and shows smaller differences between the two material-structural variants. The differences in the deformation behavior of the O (the area of the column crystals) and H (the area below the column crystals closer to the center) regions are relatively insignificant for N1 steel. There is the very sharp drop in ductility around the temperature of 1370 °C. It is clear that increasing the temperature by a few °C can lead to unexpected problems, and for N1 steel it is recommended not to exceed the temperature of 1360 °C during punching.

In the case of steel 42CrMo4, the threshold temperature for punching appears to be even lower, namely approximately 1340 °C. Even in this case, the drop in ductility is very sudden, which signals the considerable sensitivity of the steel to overheating, or burning during heating. The formability of this material is relatively significantly reduced in the area below the boundary of columnar crystals closer to the center of the continuously cast semi-finished product (H).

It would be important to find out the temperatures corresponding to the punching process at which the formability of both steels is the highest. They are likely to be lower than 1320 °C, but this would need to be verified by further testing. The question is also how a decrease in temperature would affect the energy-strength parameters of skew rolling – for this, the temperature dependence of the deformation resistance would have to be determined (e.g. by uniaxial pressure tests).

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