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ARCHIVES OF METALLURGY AND MATERIALS

Volume 60 2015 Issue 4

DOI: 10.1515/amm-2015-0448

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THE ASSESSMENT OF THE COLD PLASTIC WORKABILITY OF 20MnB4 STEEL WIRE ROD

OCENA ZDOLNOŚCI DO PRZERÓBKI PLASTYCZNEJ NA ZIMNO WALCÓWKI ZE STALI 20MnB4

The paper presents the results of cold upsetting testing of 16.5 mm-diameter 20MnB4 steel wire rod. The main purpose of the study was to evaluate the ability of wire rod produced in industrial conditions for further cold metal forming. Due to the fact that cracks occurred in the test material at different strain values, the authors made an attempt to answer the question whether there are any crack initiators in the material structure, or the observed cracks are due to the manufacturing process parameters.

In order to determine the causes of cracks appearing during upsetting tests, micro- and macroscopic observation techniques were used. For the macroscopic examination, an Olympus SZ-31 microscope was used, while a Nikon Ma-200 microscope was employed for the microscopic examination. The microscopic examination was carried out both in a light and dark fields. To evaluate the effect of surface topography on the crack formation tendency, the results of macroscopic observation under a magnification from 6.7x to 45x were used.

Keywords: technological properties, plasticity, cold upsetting test, microscopic examination, 20MnB4 steel grade

W pracy przedstawiono wyniki badań próby spęczania na zimno walcówki o średnicy 16,5 mm ze stali 20MnB4. Głównym celem pracy była ocena zdolności do dalszej przeróbki plastycznej na zimno walcówki produkowanej w warunkach przemysłowych.

W związku z tym, że w badanym materiale pojawiały się pęknięcia przy różnych wartościach odkształcenia, autorzy podjęli próbę odpowiedzi czy istnieją inicjatory pękania w strukturze materiału, czy też zaobserwowane pęknięcia są skutkiem procesu wytwarzania.

W celu określenia przyczyn pojawiających się pęknięć w takcie próby spęczania zastosowano techniki obserwacji mikro i makroskopowej. Do oceny makroskopowej zastosowano mikroskop firmy Olympus SZ-31, natomiast do oceny mikro - mikroskop Nikon Ma-200. Badania mikroskopowe przeprowadzono w polu jasnym i ciemnym. Do oceny wpływu topografii powierzchni na skłonność do tworzenia pęknięć wykorzystano wyniki obserwacji makroskopowej z powiększeniami od 6,7x do 45x.

1. Introduction

The development of computerized methods in mathematical modelling of actual technological processes provides wide possibilities for predicting the behaviour of materials under different conditions of their processing based on the knowledge of the material parameters determined during standard structural examination, mechanical and plastic testing, etc. [1, 2]. However, some real technological processes are complex, and the number of their parameters that must be considered to obtain the adequate description of the course of the process and the behaviour of the material is very large [1]. The experimental identification of those parameters goes beyond the scope of standard testing. Moreover, materials exhibit natural non-uniformities of properties, which provides an added impediment to any theoretical analyses [1]. In such instances, using relatively simple technological trials [3÷7] becomes fully warranted. In addition, many technological trials, proven in practice, are the subject of standard prescriptions [1].

The core of these trials is to test model specimens made of a given material for behaviour under conditions identical or similar to those occurring in a specific technological process or operation. The analysis of the obtained results enables the assessment of the degree of material suitability for processing in a given process or technological operation.

Materials suitable for plastic forming should exhibit the ability to be plastically deformed, while retaining coherence. This characteristic is generally referred to as plasticity, plastic properties or deformability [1].

Usually it is not possible to determine definitely whether a given material lends itself for being formed in a specific process of plastic working operation, or not, based on the

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knowledge of its plastic properties, e.g. elongation or reduction in area. This is due to the unique characteristics and conditions of the conducting of processes, and especially the occurrence of diverse stress and strain states in individual phases of formation, even within a single product being formed [1].

Therefore, the assessment of the suitability of a material for plastic forming requires additional tests to be carried out in order to identify the constitutive parameters that are necessary for mathematical modelling of the complex forming process, which will consider the phenomena of decohesion and stability loss.

An alternative is to perform relatively simple tests for engineering properties. For bars or wire rod, the assessment of deformability (especially cold deformability) is made, e.g., by upsetting and bending tests [1].

One of the techniques for determining the time of formation of a crack that could initiate a failure in the subsequent production stages is by examining the material microstructure in a dark field. This technique is especially useful for contrast highlighting the grain boundaries of metals and alloys, cracks and other surface topography features [8]. It reveals, among other things, the network of oxides that stretches out across grain boundaries.

The light field examination, on the other hand, made either on etched or non-etched microsections, enables one to search for regions in the examined material, in which discontinuities or non-metallic inclusions could exist.

2. Purpose and scope of the study

The main purpose of the study was to determine the ability of industrially produced wire rod to be further cold plastically deformed. The investigation discussed in the paper was carried out for 16.5 mm-diameter wire rod made of 20MnB4 steel [9]. The deformability of the examined steel grade was determined by the cold upsetting test performed according to Standard PN-83/H-04411 [7]. The tests were carried out on specimens with an initial height of 1.5 d and 2.0 d, respectively, where d denotes the diameter of the finished product. For each relative strain value (50 %, 66 %, 75 %), three tests were carried out.

Because of the fact that cracks came up in the tested material at varying strain values, the authors made an attempt to answer the question whether there were any fracture initiators in the material structure in the form of, e.g., cracks on the finished product surface, or the observed cracks were due to the manufacturing process.

To determine the causes of cracks occurring in the upsetting tests, the micro- and macroscopic examination techniques were used. For macroscopic assessment, an Olympus SZ-31 microscope was employed, while for microscopic examination – a Nikon Ma-200 microscope. The microscopic examinations were performed in a light and dark fields. The results of macroscopic observations under magnifications from 6.7x to 45x were used for the determination of the effect of topography on the tendency to crack formation.

3. Analysis of the investigation results

Chemical composition of the investigated steel grade is given in Table 1.

A general view of wire rod of the steel grade under investigation and microsections are shown in Fig. 1.

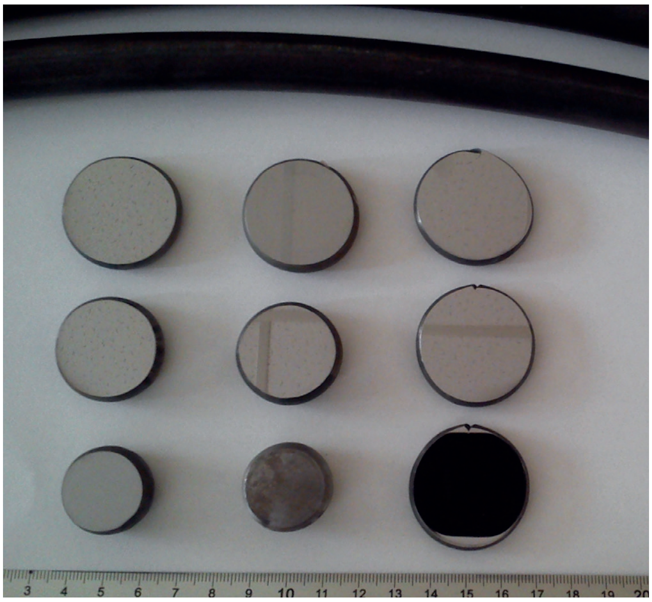

Fig. 1. 16.5 mm-diameter 20MnB4 steel wire rod and test specimen microsections

A general view of 16.5 mm-diameter 20MnB4 low-carbon steel specimens after the cold upsetting process is shown in Figure 2.

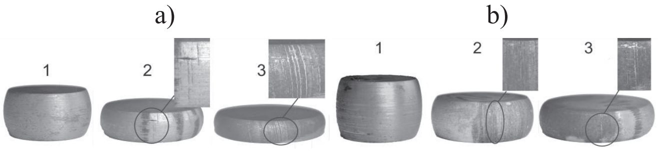

Fig. 2. A general view of 16.5 mm-diameter 20MnB4 steel specimens after the cold upsetting process: a) specimens with a height of 1.5 d; b) specimens with a height of 2.0 d; 1 – relative plastic strain of 50%; 2 – relative plastic strain of 66%; 3 – relative plastic strain 75%

The macroscopic observation of the finished product

TABLE 1

Chemical composition of 16.5 mm-diameter 20MnB4 steel wire rod according to the melt analysis

Component contents [%]										
C	Mn	Si	P	S	Cr	Ni	Cu	Al	Mo	Sn
0.21	0.97	0.10	0.014	0.009	0.26	0.07	0.17	0.024	0.014	0.012
N	Pb	Almet.	Ca	As	Cb	V	Ti	B	Zn	Ceq.
0.0119	0.001	0.020	0.002	0.007	0.002	0.004	0.047	0.0030	0.018	0.44

surface found longitudinal cracks to occur on the examined wire rod surface. An example of this type of cracks under a magnification of 45 x is illustrated in Fig. 3.

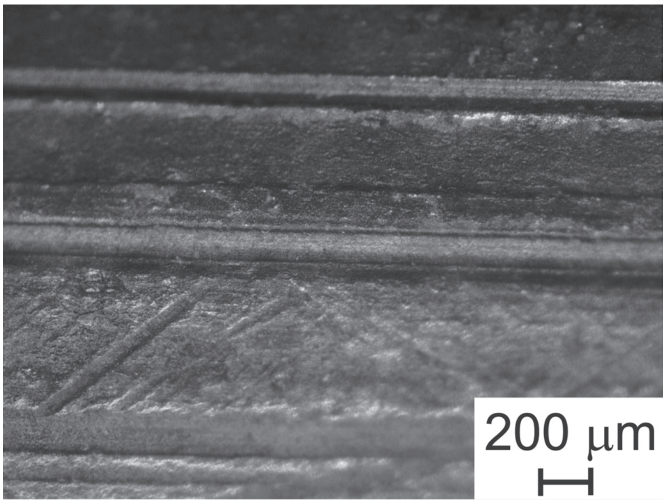

Fig. 3. The surface of 16.5 mm-diameter 20MnB4 steel wire rod with visible longitudinal cracks – magnification 45 x.

In the authors' view, there are several causes of the occurrence of the above-mentioned surface defects. The first of them could be the excessive wear of the passes in the finishing arrangement, and the second one – incorrect setting of rolling line equipment (e.g. the loop layer). The macroscopic assessment of surface cracks (Fig. 4) occurring on the test specimens subjected to upsetting showed that, because of the rounded shape of their bottom, the surface cracks themselves were not the immediate cause of the initiation of cracks occurring during the cold upsetting test.

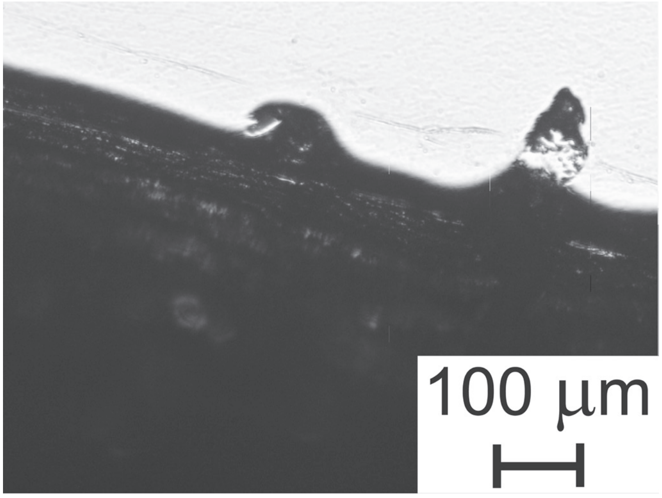

Fig. 4. A microphotograph of 16.5 mm-diameter 20MnB4 steel wire rod surface with a visible longitudinal crack – the cross-section

From the results of the macro- and microscopic examinations of specimens subjected to deformation with a 50% relative strain, only small sub-surface cracks were found to occur. Figure 5 shows example macro- and microscopic images of a specimen with an initial length equal to 1.5 d, deformed with a relative strain of 50%. The length of the observed discontinuities in both cases (i.e. for the specimens with the initial length equal to 1.5 d and 2.0 d) did not exceed approx. 100 µm and did not exhibit a tendency to further cracking.

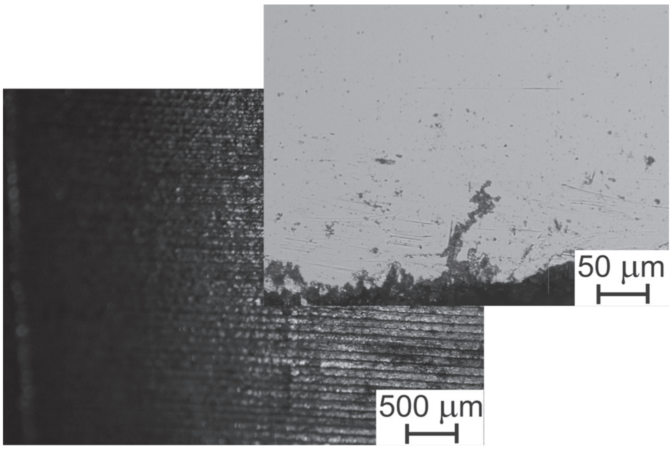

Fig. 5. A surface crack on a 20MnB4 steel specimen with an initial length of 1.5 d – relative strain 50%.

The macro- and microscopic examinations of specimens subjected to deformation with a 66% relative strain found the occurrence of much deeper and sharper cracks. The length of the observed cracks was from approx. 1 mm (for 1.5 d specimens) to over 3 mm (for 2.0 d specimens). An example of this type of cracks is shown in Fig. 6.

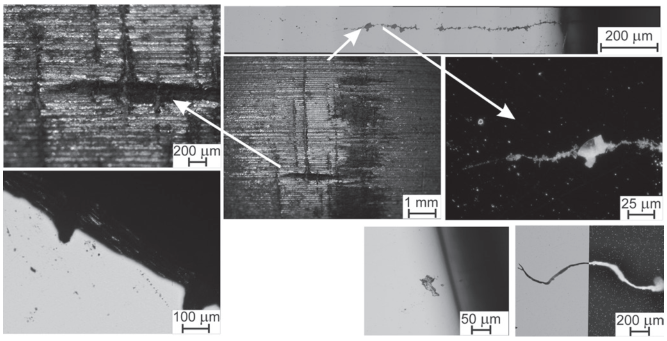

Fig. 6. Macroscopic and microscopic views of cracks on 1.5 d-initial length 20MnB4 steel specimens – relative strain 66%

The analysis of the data represented in Fig. 6 shows that the occurrence of longitudinal cracks (Figs. 3 & 4) does not initiate the cracking process even at a relative strain of 66%. However, two possible cracking (failure) initiators were observed to occur in the test specimen. The first of them were visible sub-surface non-metallic inclusions occurring at a distance of up to 200 µm from the surface (Fig. 6). The second cracking initiator were unbonded discontinuities (voids) of metallurgical origin, also observed in the border zone. Studies carried out at the authors' home research unit [10÷12] identified this type of defects to have occurred in a steel production and processing plant, which very adversely affected the finished product properties. From the investigation it was found that the synergic effect of non-metallic inclusions and an unbounded discontinuity might be the cause of cracks occurring both along the deformation direction and in the transverse direction.

The examination of a crack with a length of over 3 mm, shown in Fig. 7, did not provide the definite answer to the question of what had initiated the cracking process. Admittedly, small quantities of non-metallic inclusions were also visible in the sub-surface region, but no presence of pores or their remnants was observed anywhere. There is high likelihood that, similarly as for the 1.5 d-initial length specimen deformed with a relative strain of 66% (Fig. 6), in the case under consideration too, the cracking initiator were inclusions, all the more so because the cracks well visible under microscopic observation are not the locations where the breaking of the material occurred. The visible crack is linear in character.

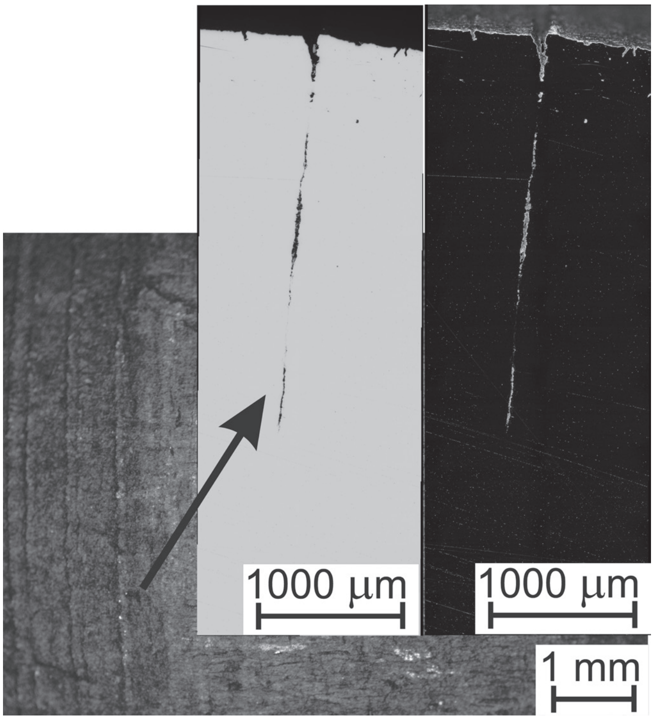

Fig. 7. Macroscopic and microscopic views of fractures and cracks on the 2.0 d-initial length 20MnB4 steel specimen – relative strain 66%

Figures 8 and 9 illustrate specimens deformed with a relative strain of 75%. On both specimens (with the initial length equal to 1.5 d and 2.0 d), small cracks were observed to occur, whose bottom had a rounded shape.

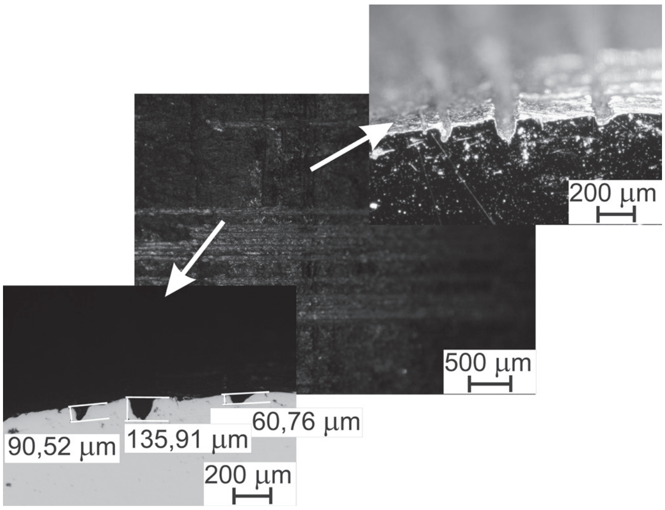

Fig. 8. Macroscopic and microscopic views of fissures and cracks on the 1.5 d-initial length 20MnB4 steel specimen – relative strain 75 %

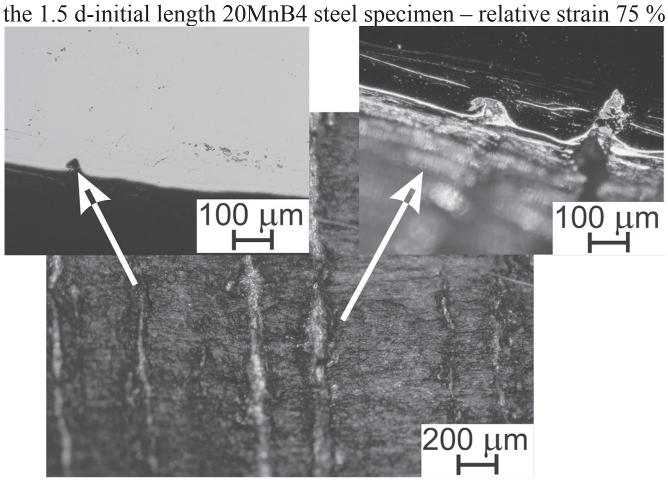

Fig. 9. Macroscopic and microscopic views of fractures and cracks on the 2.0 d-initial length 20MnB4 steel specimen – relative strain 75 %

Further examinations found high non-uniformity of the properties of the examined steel grade along the finished product length, as demonstrated by the example specimen with a visible deep crack, which was obtained with a relative strain of 75% and is shown in Fig. 10 and Fig. 11.

Fig. 10. A general view of a 20MnB4 steel specimen after the cold upsetting process with a relative strain of 75%

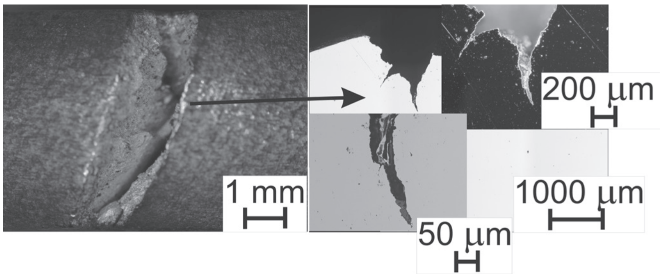

Fig. 11. Example macroscopic and microscopic views of cracks on a 20MnB4 steel specimen – relative strain 75%

The size of the observed crack did not allow all possible causes of its origin to be definitely determined. Judging by its size, the crack is complex in character, and its initiators may be both inclusions and discontinuities, as well as incorrect heat treatment parameters. The cumulation of all of the above-mentioned factors can cause cracks of that particular size.

From the analysis of the cold upsetting test results it has been found that the 16.5 mm-diameter 20MnB4 steel wire rod rolling technology being currently in use ensures the properties of finished product in a relative strain range of up 50%. At higher plastic strains, cracks and deep fissures start to occur in the material, which disqualifies it from further cold plastic working. Based on the investigation carried out and upon the analysis of the investigation results it has been ascertained that the cause of those cracks, in addition to rolling and cooling process parameters, can also be surface defects formed in the production process, or defects of metallurgical origin (such as non-metallic inclusions – impurities and internal discontinuities).

4. Summary and conclusions

In accordance with the applicable standards, wire rod of cold upsetting steel should be characterized by a minimum relative plastic strain of 50% and an upset specimen heigh index of 0.5. However, because of the constantly growing customer requirements, efforts are being currently made to improve the quality of produced wire rod so that it will able to be cold deformed with a plastic strain of 66% (an upset specimen height index of 0.33) and recently even 75% (an upset specimen height index of 0.25). In view of the scarcity of detailed data available in the technical literature on the technology of upsetting steel wire rod cold rolling in modern wire rod rolling mills, it becomes justified to undertake investigations aimed at improving the quality of products manufactured there.

Upon carrying out the investigation of the cold plastic workability of 16.5 mm-diameter 20MnB4 steel wire rod and analyzing the obtained results, it has been found that:

- the currently used technology of rolling 16.5 mm-diameter wire rod of 20MnB4 steel allows its further cold plastic working with a relative strain of up to 50%;
- when relative strains greater than 50% are used, cracks and fissures will occur in the material concerned, which disqualifies it from further cold plastic working;
- the cause of occurring cracks may be both incorrectly chosen thermoplastic treatment parameters and surface defects formed in the production process, as well as defects of metallurgical origin.

Acknowledgements

This research work was financed from the resources of the National Research and Development Centre (Narodowe Centrum Badań i Rozwoju) in the years 2013÷2016 as Applied Research Project No. PBS2/A5/0/2013.

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Received: 15 September 2014.