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AN INVESTIGATION OF THE STRETCH REDUCING OF WELDED TUBES

RAZISKAVA IZTEZNE REDUKCIJE VARJENIH CEVI

Stoja Rešković[1], Franc Vodopivec[2]

[1]Faculty of Metallurgy, University of Zagreb, Sisak, Croatia
[2]Institute of Materials and Technology, Ljubljana, Slovenia
reskovic@simet.hr

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The results of an investigation into the hot stretch reducing of high-frequency welded steel tubes are presented. The internal stresses were determined after every processing pass. The selected processing parameters ensured that the coefficient of plastic extension was maintained in the range that prevents the tearing of the tube wall and achieves the required geometrical shape as well as the planned properties of the finished tube.

Key words: welded tube, hot stretch reducing, micro-alloyed steel, internal stresses, coefficient of plastic extension

Predstavljeni so rezultati raziskave iztezne redukcije visokofrekvenčno varjenih jeklenih cevi. Po vsakem prehodu so bile določene notranje napetosti. Izbrani procesni parametri zagotavljajo, da se koeficient plastičnega podaljška ohranja v razponu, ki preprečuje trganje cevne stene in zagotavlja, da se dosežejo predpisane mere in mehanske lastnosti cevi.

Ključne besede: varjene cevi, vroče iztezna redukcija, mikrolegirano jeklo, notranje napetosti, koeficient plastičnega podaljška

1 INTRODUCTION

With proper hot working small additions of micro-alloying elements can improve the properties of hot-rolled sheets produced from structural steels [1,2]. Hot-rolled welded tubes are manufactured from hot-rolled sheets with carbide precipitates formed by deformation-induced precipitation during the final stages of hot rolling. In the technology of the stretch reducing of welded tubes, the initial tube blank is processed at an appropriate temperature and without internal tool (mandrel) to a different diameter and wall thickness [3]. The calculation of the per-pass reductions of the tube diameter and the wall thickness is relatively complex [3,4,5], and their proper sequence depends on the type of steel, the rolling temperature and the rate and the extent of reduction of the tube's diameter and the wall thickness. In this study the results of an experimental investigation on the evolution of the microstructure and internal stresses for a sequence of stretch-reducing passes for a micro-alloyed steel are presented. The findings in this investigation were used in the selection of the optimal parameters for industrial processing.

In the process of manufacturing hot-rolled welded tubes, the sheet is formed at room temperature in a tube pre-form, high-frequency welded, heated first to the normalising temperature, to homogenise the microstructure in the weld, and then heated to the hot-rolling temperature, processed with stretch-reducing passes to the required size and air cooled [5]. The processing mill consists of several three-rolls high stands [4,5].

For proper processing, a balancing of the maximum allowed changes to the tube diameter and the wall thickness is required. Achieving the final tube size depends on the maximum allowed deformation and stressing of the steel at the temperature of every processing pass. The reduction of the diameter occurs in several passes and depends on the total reduction and the number as well as the size and design of passes. In the initial processing stands of the investigated mill, the tube diameter decreased quickly to a constant value, then it decreased more slowly towards the end pass to ensure to obtain the required tube diameter and wall thickness. The deformation was 3–5 % per pass and stand [4,5]. The maximum extent of the wall reduction depends on the steel's plastic elongation, the total and the per-pass. To prevent hot tearing of the tube wall it is necessary to know for every stand, the maximum coefficient of the steel's plastic extension (stretching), which is given as a ratio of the axial stressing and the steel's elongation [4,5],and can achieve a maximum value of $Z_t = 1$.

For $Z_t = 0.5$ the wall thickness is increased, and for a reduction of the tube diameter by 3–5%, the tube length and the wall thickness are increased. Experience shows that up to $Z_t = 0.55$, the wall thickness remains unchanged. However, for $Z_t = 1$ the tube diameter and the tube-wall thickness are reduced simultaneously and tube-wall ruptures occur frequently. For this reason, the maximum value of the coefficient of plastic extension is Z_t =0.7–0.8 [4,5].

2 FRAMEWORK AND SCOPE OF THE INVESTIGATION

The fundamental processes and mechanisms of austenite hot deformation, carbide precipitation and austenite grain growth are involved in the processing of micro-alloyed steels [6]. After proper thermomechanical processing, the hot-rolled sheet has a fine-grained and homogenous microstructure and good mechanical properties [1]. With higher temperatures, coarsening of the precipitates occurs, with the kinetics depending on the temperature, the solid solubility and the diffusivity [6,7]. With a smaller solid solubility, the coarsening rate of the precipitates is reduced, and it is also less for nitride than for carbide particles [6]. Precipitates with a diameter over a critical value and at large mutual distance accelerate the static recrystallisation of austenite, while for a small mutual distance the small precipitates may even hinder the static recrystallisation of austenite [8,9,10,11]. In niobium micro-alloyed structural steels the static recrystallisation of austenite occurs at a sufficient temperature if the per-pass rolling deformation is above approximately 12 % [12,13]. In the investigated processing the per-pass reduction was below this level, and therefore the deformation energy was released only with recovery.

The large number of point and line defects introduced into the steel by the plastic deformation produces strain hardening and softening processes with a mutual relation depending on the steel's chemical composition, the initial microstructure and the extent of deformation, the rate of deformation and the deformation temperature. Hardening is the result of an increase in the density of the deformation defects and softening corresponds to a decrease. The rates of diffusion, precipitation and precipitate coarsening can be increased in non-recrystallised austenite by up to two orders of magnitude [10,11,14] when compared to that in the recrystallised austenite, and this affects significantly the density and the mobility of the vacancies and dislocations.

The precipitation rate depends on the temperature, the degree of deformation and the content of elements affecting the recrystallisation, especially niobium. In the hot-rolled sheet used in this investigation, we found mostly particles formed by deformation- induced precipitation [1]. With high-frequency welding the steel is locally heated up to 1400 °C; however, the heating time is very short and it does not produce a significant change in the size and distribution of the precipitates. With the subsequent reheating of the tube blanks to 850 °C, the microstructure in the weld area is homogenized, while the size and the distribution of the precipitates are not affected.

The initial temperature of the stretch reducing of the welded tubes depends on the number of passes and should be sufficiently high to ensure the finishing temperature is above the austenite-to-ferrite transformation [4,5]. For low-carbon steel it is in the range 1100–950 °C. During soaking, coarsening of the austenite grains occurs and part of the niobium carbonitride is dissolved in austenite, as the solid solubility is attained only at a higher temperature. Parallel coarsening of the non-dissolved precipitates could also occur.

In the process of mastering the technology of stretch reducing high-frequency welded tubes from niobium micro-alloyed steels, in the central passes of the processing line tearing of the tube wall occurred frequently, especially in the weld area. The aim of this work was to investigate the microstructure processes that may be related to the tearing. In the frame of the investigation the microstructure, the mechanical properties and the evolution of the internal stresses generated by the deformation were investigated.

3 EXPERIMENTAL WORK

In **Tables 1 and 2** the chemical composition of the steel and the mechanical properties of the sheet determined from specimens cut out from the initial, centre and end of the coil, are shown. The microstructure of the steel sheet consisted of fine polygonal ferrite and pearlite grains (**Figure 1**).

Table 1: Composition of the steel, *w*
Tabela 1: Sestava jekla, *w*

C	Mn	Si	P	S	Al	Nb	O2	N2
0.14	0.8	0.12	0.011	0.018	0.005	0.049	0.005	0.009

The 370 mm × 3.6 mm steel band of the required length was cut out from the coil, then it was shaped to a tube blank with a diameter of 117 mm, which was high-frequency welded [15], heated to 850 °C for the homogenisation of the microstructure and the relaxation of the internal stresses, then heated to the hot-working temperature and processed within the temperature range 960–830 °C. In **Figure 2** the microstructure is shown for different parts of the welded tube: the section of the weld, the heat-affected zone, the base material and the weld. The weld is narrow and the microstructure of the

Table 2: Mechanical properties of the sheet
Tabela 2: Mehanske lastnosti traka

	R_e/MPa		R_m/MPa		A_5/%		K_{cv}/(J/mm^2)	
Direction	Axial	Transv.	Axial	Transv.	Axial	Transv.	Axial	Transv.
Coil onset	500	492	599	590	32.5	29.8	123	147
Coil centre	496	490	592	586	30.5	30.3	120	138
Coil end	495	495	590	576	30.1	31.9	118	127

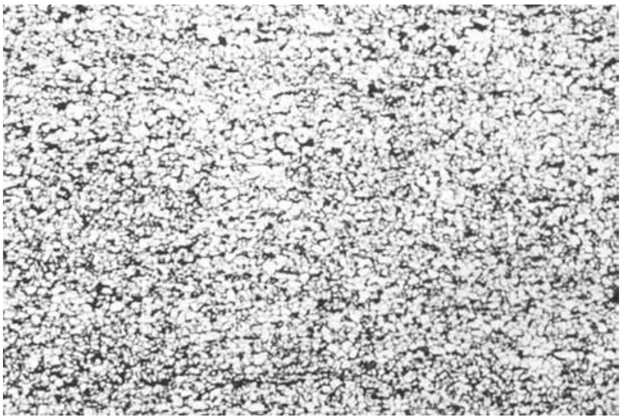

Figure 1: Microstructure of the sheet
Slika 1: Mikrostruktura traku

characteristic heat-affected zones is similar to that in the standard welds of structural steels [15].

The reduction to the final size of *d* 48.3 mm × 3.2 mm is achieved in 12 passes, applying a per-pass deformation, preventing the tearing of the tube wall, the achieving of the final diameter and ensuring that the final pass temperature is just above the austenite-to-ferrite transformation point, which strongly affects the properties of the steel in the finished tube.

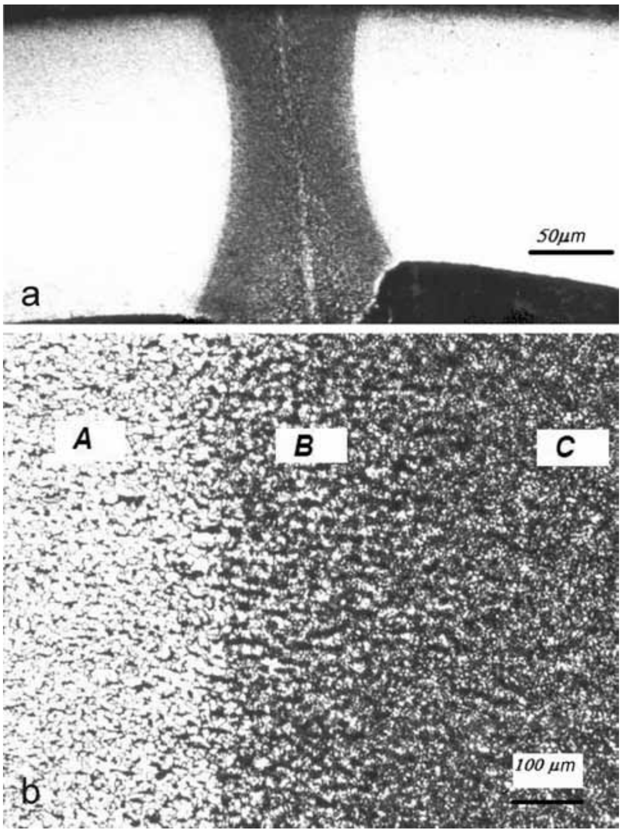

Figure 2: Tube-weld area **a)** macrography of the weld section, **b)** micrography of the welding area: A- base steel, B – heat-affected zone, C – weld
Slika 2: Področje zvara cevi **a)** makrografija prereza zvara, **b)** mikrografija področja zvara: A – osnovno jeklo; B – toplotma zona, C – var

The tests and examinations were carried out on samples of A, a hot rolled sheet; B, a welded tube; C, a tube after heating to the rolling temperature and water quenching, and D, a finished tube. At 12 selected points of the processing, the mill was stopped and the samples of the so-far processed tube 1 to 12 were cut out and air cooled or water quenched. Using these samples the diameter of the tube and the thickness of the tube wall were checked and the specimens for mechanical tests and optical microstructure examinations were prepared. Carbide and carbonitride particles were extracted from the steel with electrolytic dissolution and identified with X- ray diffraction analysis. For the identification of the phases found in isolates the data in [16,20] were used. The internal stresses were determined on specimens with a finely ground and etched surface. The Debye diffraction lines were checked for the wavelength and the (310) peak of α-iron, the widths of the (110), (200) and 211) lines for iron were assessed at half intensity and the internal stresses were deduced quantitatively using the method proposed in [17,18,19].

4 RESULTS AND DISCUSSION

4.1 Processing parameters

From the data obtained on samples cut out from the tube after all stretch reducing passes the partial deformations shown in **Figures 3 and 4** were deduced. The pass temperature is also given in both figures. The per-pass decrease of the tube diameter is large and virtually constant in the initial 7 passes, after this it decreases. The decrease of the tube diameter depends on the processing procedure. As a rule, the stretch reducing in the first passes results in the maximum decrease of the tube. In **Figure 3** a decrease of 57 % of the tube diameter was obtained in the first four passes. The wall thickness is achieved by stretching, and it depends strongly on the steel extension in every pass that is lower in the previous passes [4,5]. On the investigated mill the drawing reduction of the wall thickness of the structural steel occurs in the

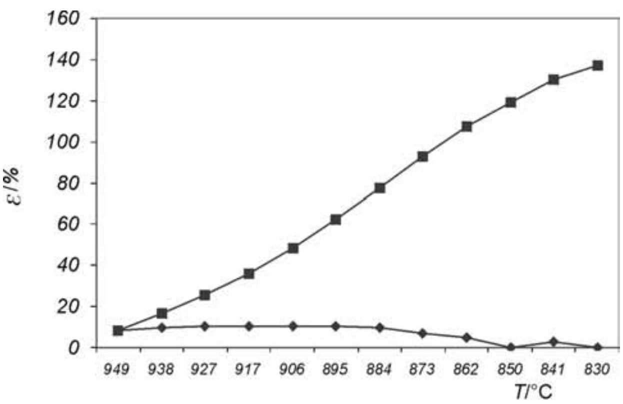

Figure 3: The per-pass (◆) and total (■) reduction of the diameter
Slika 3: Redukcija premera cevi, na vtik (◆) in skupna (■)

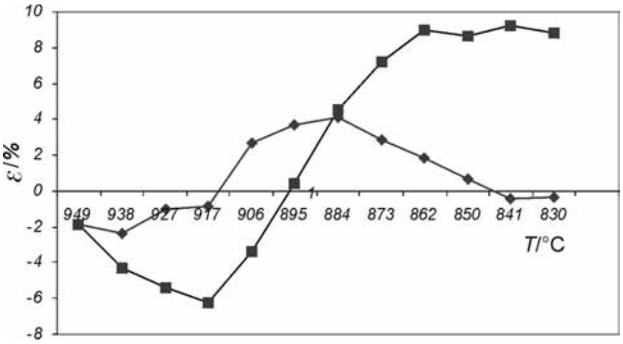

Figure 4: The per-pass (◆) and total (■) reduction of the thickness of the tube wall

Slika 4: Redukcija debeline stene cevi, na vtik (◆) in skupna (■)

temperature range from 1000 °C to 800 °C by the value Z = 0.6–0.72, and a maximum per-pass wall reduction of 2 %. For the processing of niobium micro-alloyed steel, the maximum coefficient of plastic extension is lower, i.e., Z = 0.65 % (**Figure 5**). The required tube diameter and tube-wall thickness can be achieved only with smaller per-pass reductions and, accordingly, the value of the coefficient of plastic extension is lower also.

The curve of total deformation in **Figure 3** was found to be virtually ideal for the processing of the investigated tube on the used stretch-reducing line, as the deformation parameters in **Figure 5** ensured stable processing and the required size and properties of the tube.

In the range of the analytical accuracy, the content of niobium carbo-nitride was equal for all the specimens [20]. This confirms the assumption that the content of niobium carbide is not affected by the processing parameters. It is interesting that in the weld a small quantity of niobium nitride was also detected.

4.2 Internal stresses

The difference in the shapes of the X-ray diffraction spectra for the base material and for the weld is very

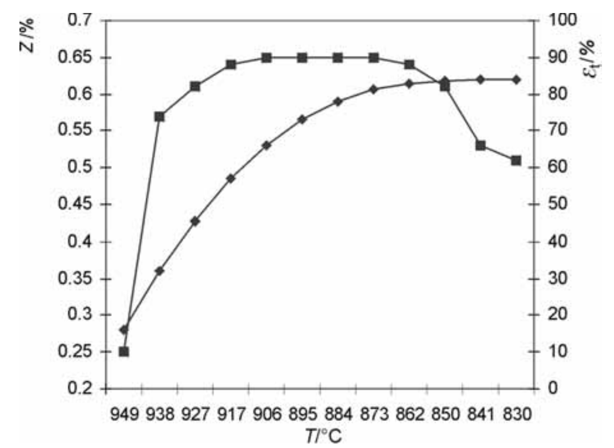

Figure 5: Change of Z(■) and the total reduction of tube ε_t (◆) in stretch reducing

Slika 5: Sprememba Z(■) in skupna redukcija cevi ε_t (◆)

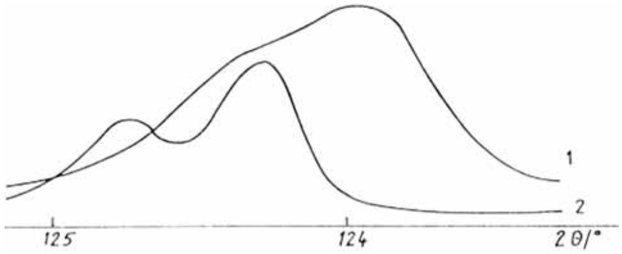

Figure 6: Welded tube. Profile of the diffraction lines (220) for the weld (1) and the base steel (2).

Slika 6: Zvarjena cev. Profil uklonskih črt (220) za zvar (1) in za osnovno jeklo (2)

clear (**Figure 6**). Since ferrite is the matrix in both cases, the absence of the Kα doublet confirms the presence of internal stresses in all the specimens water quenched from the processing temperature and used for the X-ray examination. After hot plastic deformation, the profile of the diffraction line is similar, and this indicates a partially homogenised microstructure (**Figure 7**); however, the internal stresses are still slightly greater in the weld. The diffraction line for the base material is virtually equal for the blank and the processed tube, although it is very different for the weld. The presence of the Kα doublet after stretch reduction indicates that the hot deformation had a favourable effect on the microstructure and on the internal stresses in the weld.

The intensity of internal stresses after the following processing passes is shown in **Figure 8**. The stresses remain constant in the specimens up to the third pass, then increase quickly in the following six passes, with a constant coefficient of plastic extension, and then gradually decrease in subsequent passes, parallel to a decrease in the coefficient of plastic extension. The evolution of stresses is virtually equal for the base material and the weld, and this indicates an identical reaction of both to the deformation and the equal extent of the interpass softening processes. It also confirms that the applied thermal regime of the tube blank before the start of the stretch reducing helped to avoid a greater intensity of internal stresses and a greater propensity for tearing of the tube wall in the weld area.

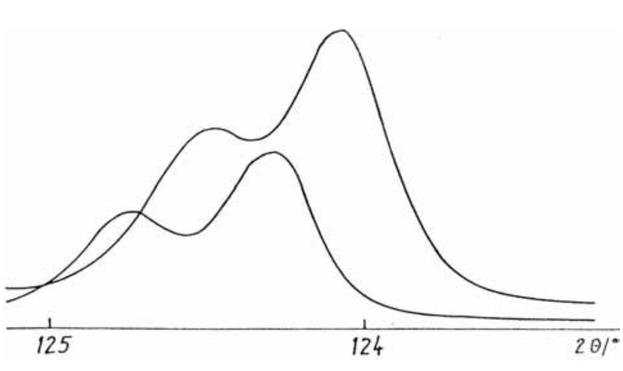

Figure 7: Finished tube. Profile of the diffraction lines (220) for the weld 1) and the base steel (2).

Slika 7: Izdelana cev. Profil difrakcijskih črt (220) za zvar (1) in za osnovno jeklo (2)

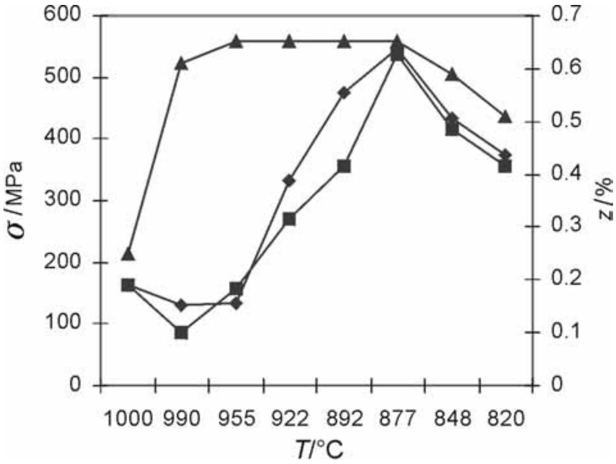

Figure 8: Evolution of internal stresses (weld ◆, base material ■) and coefficient of plastic extension Z (▲) with respect to the processing temperature.

Slika 8: Evolucija notranjih napetosti (var ◆, osnovni material ■) in koeficient plastičnega podajška Z (▲) v odvisnosti od temperature predelave

The faster cooling of the specimens for the X-ray examination explains why the internal stresses are even greater than the yield stress determined for the air-cooled specimens. The internal stresses are greater for a greater density of lattice defects generated by the plastic deformation of austenite and the decreasing extent of the recovery due to the lowering of the processing temperature. It is logical to assume that with an increased density of lattice defects the steel's hot workability is lower and that the relation between the stresses in different specimens is preserved after quenching. The first assumption is confirmed by the fact that the tube-wall tearings were more frequent for the passes with greater internal stresses and the second is the difference in the level of internal stresses for the specimens quenched after a different total deformation. In the range of the increase of the internal stresses the per-pass deformation was constant. The stresses were determined from X-ray spectra at room temperature and these are not equal to the stresses at the processing temperature. In reality, the stresses are a relative measure of the extent of the release of deformation hardening and of the residual deformation capacity of the steel, which are of essential importance for the smooth operation of the stretch-reducing line. On the basis of the assessment of the intensity of internal stresses and of the processing experience it can be concluded that the increased internal stresses due to the incomplete release of the deformation energy with interpass recovery and the lowering of the workability can be balanced with the selection of the proper value of the coefficient of plastic extension.

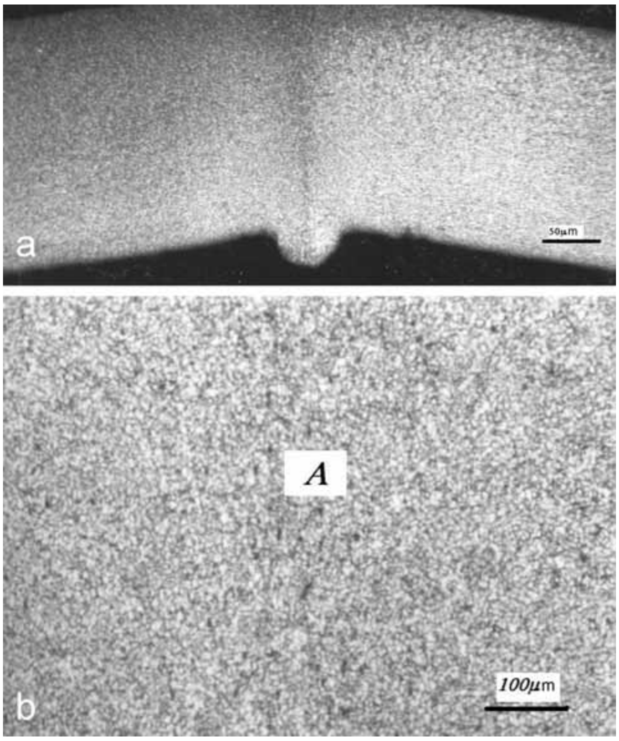

Figure 9: Section and microstructure of the finished tube wall in the weld area (A – weld zone)

Slika 9: Prerez in mikrostruktura stene cevi v področju zvara (A – področje zvara)

4.3 Properties of the finished tube

The mechanical properties determined for the sections of the tube with a weld and without a weld and are shown in **Table 3**. The very fine grain size (**Figure 9**) ensures that the tube has excellent mechanical properties, in accord with the standard requirements.

The mechanical and technological properties are virtually equal for the weld and the base material and confirm that the temperature-deformation regime made it possible to achieve a sufficient degree of homogenisation of the microstructure of the weld and the base material, the processing without tube-wall tearings, and the good mechanical properties of the finished tube.

Table 3: Mechanical and technological properties of the finished tube

Tabela 3: Mehanske lastnosti izdelane cevi

Spec.	R_e/MPa		R_m/MPa		A_5/%		K_{cv}/(J/mm^2)	
	Weld	B.mat.	weld	B.mat.	Weld	B.mat.	weld	B.mat.
1	502	497	590	596	32.5	31.7	104	110
2	495	492	592	609	32.5	32.7	101	122
3	496	500	592	603	31.9	32.01	106	112

5 CONCLUSIONS

The quality and reliability of the hot stretch reducing of high-frequency welded tubes depend strongly on the understanding of the processes in the steel at the operating temperature and the mastering of these processes in individual passes as well as during the entire processing line.

With the initial heating of the welded blank a sufficient homogenisation of the weld and base material's microstructure and the internal stresses were achieved. The initial hot-working temperature ensured the steel had sufficient ductility on the processing line and a sufficient finishing temperature above the austenite-to-ferrite transformation.

The per-pass changes of the tube diameter and the wall thickness ensured a smooth processing without any tube-wall tearings.

Of great importance to mastering the hot stretch reducing of tubes was understanding the per-pass evolution of the internal stresses and the choice of the per-pass deformation parameters, ensuring that we maintain the optimum value of the coefficient of plastic extension.

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