# THE EFFECT OF HEAT TREATMENT PARAMETERS ON CREEP CHARACTERISTICS OF THE 10CrMo9-10 STEEL TUBE BENDS

JUNAK Grzegorz[1], CIEŚLA Marek[1], FINDZIŃSKI Rafał[1]

[1]*Silesian University of Technology, Faculty of Materials Engineering and Metallurgy, Institute of Materials Science, Katowice, grzegorz.junak@polsl.pl*

**Abstract**

The purpose of the paper was to analyse the effect of diverse heat treatment parameters (normalising and tempering) on mechanical characteristics of ∅508 x 20 x 90° tube bends made of the 10CrMo9-10 steel manufactured by bending with local induction heating. The research comprised tests of basic mechanical properties and creep at the temperature of 500 °C. With reference to the results thus obtained, it has been established that there is a relationship between mechanical properties of samples and individual features of their microstructure. Heat treatment parameters triggered changes to the microstructure of the bends, compared to an as-delivered tube. These effects included a change of strength characteristics ($R_m$, $R_{p0,2}$) and material creep lifetime, as compared with the tube. Heat treatment at a lower temperature and shorter tempering time assured the longest creep lifetime. It has also been found that the main structural factor determining creep lifetime of bends is grain size.

**Keywords:** 10CrMo9-10 steel, heat treatment, tube bending, mechanical properties, creep

## 1. INTRODUCTION

The fundamental criterion applied when choosing steel tubes for purposes of the power engineering industry is the creep characteristics of tubes in the as-delivered condition [1, 2]. These characteristics also provide grounds for projecting service life of individual power systems. Results of the studies addressed in the paper imply that mechanical characteristics of material samples collected at different zones of tube bends, including creep characteristics, are considerably diversified compared to the tube material in the as-delivered condition [3, 4]. Consequently, service life projecting and assessment of the pipeline system reliability may be encumbered with errors, all the more since the effort of material is typically higher at tube bends than in straight pipeline sections.

Tube bends are used in virtually all pipelines intended for the power industry. It is also increasingly common that their manufacturing technologies rely on non-conventional methods involving application of local heating of tubes while bending [5-9].

As the grounds for the research, it was considered reasonable to undertake studies aimed at identification of the effect of diversified NT heat treatment parameters on mechanical properties of tube bends manufactured with local induction heating. The material subject to tests comprised ∅508 x 20 tubes made of the 10CrMo9-10 steel in the as-delivered condition as well as two tube bends made from them, characterised by the bending angle of $\phi$ = 90° and the bending radius of R = 762 mm. They were examined for microstructure and basic mechanical properties, and were subject to creep testing at the temperature of 500 °C.

## 2. TEST MATERIAL

Tests were conducted using material samples collected from an as-delivered tube as well as from tube bends manufactured on diverse heat treatment parameters. The tube bends, whose geometric features have been summarised in **Table 1**, were subject to NT treatment (normalising and tempering) with parameters provided in **Table 2**.

**Table 1** Geometric properties of tube bends of ∅508 x 20, R = 762 mm and ϕ = 90 °.

| Test material | Tube wall thickness [mm] | | Cross-section ovalisation [%] |
|---|---|---|---|
| | Compressed zone $g_w$ | Tensioned zone $g_z$ | |
| Industrial trial #1 | 27.6 | 18.2 | 4.6 |
| Industrial trial #2 | 31.7 | 18.5 | 4.8 |
| PN-EN 12952, PN-EN 13480 standard requirements | >18 | >15 | <10 |

**Table 2** Test material condition

| Test material description | Heat treatment parameters |
|---|---|
| Tube | in as-delivered condition |
| Tube bend "1" (HT variant 1) | Normalising: 940°C, 20 min, tempering: 740°C, 30 min |
| Tube bend "2" (HT variant 2) | Normalising: 920°C, 20 min, tempering: 720°C, 20 min |

Test samples were prepared by collecting them from the material subject to testing in a direction transverse to the tube axis and from tube bends, as shown in **Figure 1**.

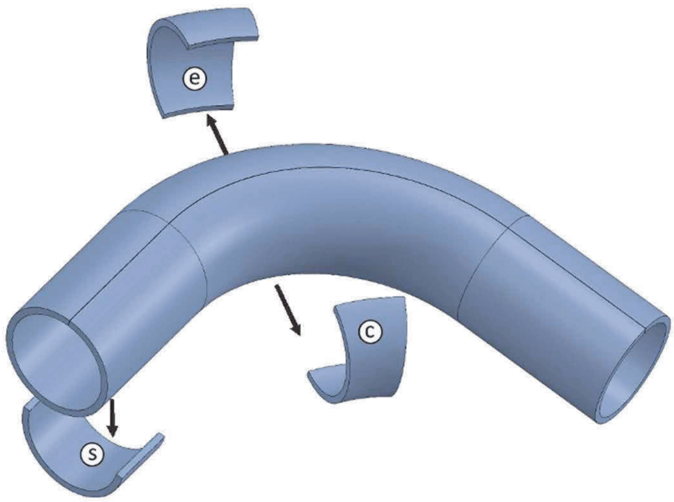


**Figure 1** Locations of tube bend zones from which samples were collected for material testing: s - section straight, e - tensioned (extended) bend zone, c - compressed bend zone.

## 3. RESULTS OF MATERIAL TESTS

The microstructure of the material samples subject to tests was analysed by means of the Olimpus light microscope. The observations conducted in the tube material revealed its microstructure to be bainitic with ferritic regions. In the material of tube bends, ferritic-bainitic microstructure was found, featuring finer grain in the compressed and the tensioned zone as well as with distinctive banding compared to the microstructure of the tube bend's straight zone. Using the MetIlo-12.1 computer program, average size of the "Ā" primary austenite grain found in the microstructure of the bend's tensioned zone was measured [10]. Sample microstructures of the tube and the bend material have been shown in **Figures 2-5**.

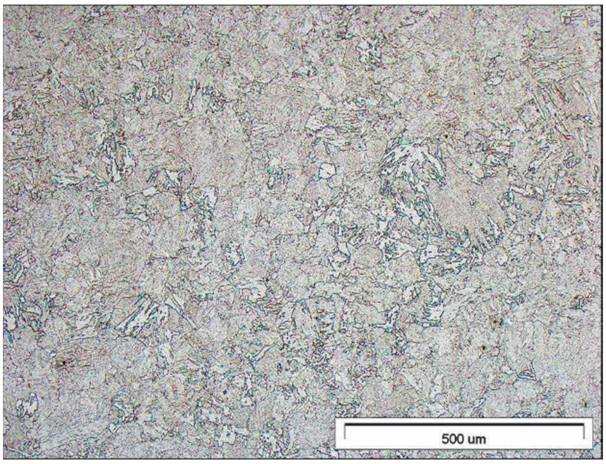


**Figure 2** Bainitic microstructure of an as-delivered tube

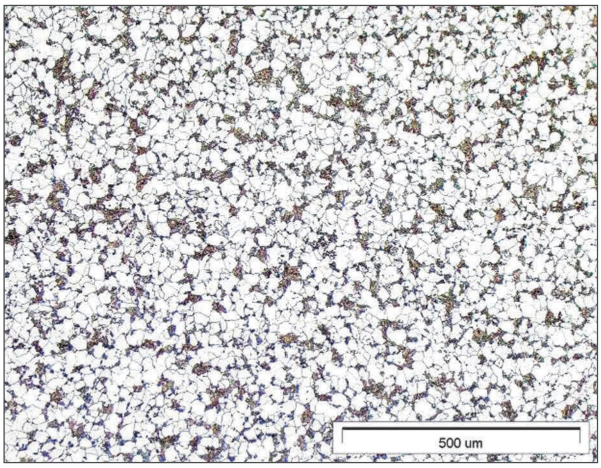


**Figure 3** Ferritic-bainitic microstructure of tube bends straight section

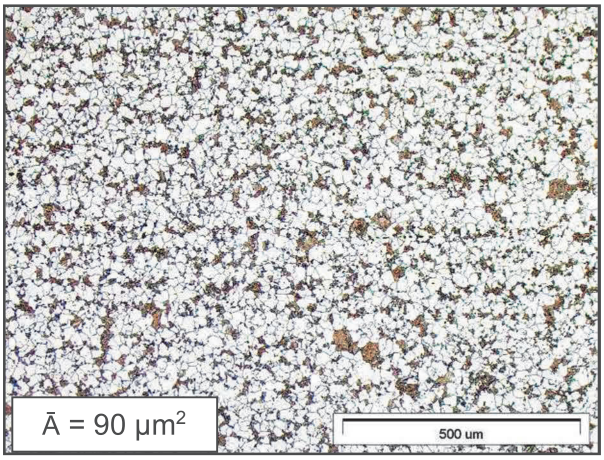


**Figure 4** Ferritic-bainitic microstructure banding in the tensioned zone of tube bend “1”

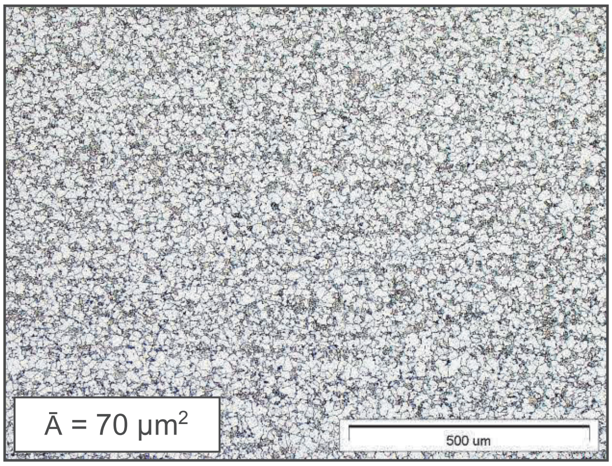


**Figure 5** Ferritic-bainitic microstructure banding in the tensioned zone of tube bend “2”

**Table 3** Basic mechanical properties of as-delivered tubes and tube bends

| Material | | Room temperature | | | | | Temperature of 500 °C |
|---|---|---|---|---|---|---|---|
| | | $R_m$ [MPA] | $R_e$ [MPa] | A [%] | HV10 | KV [J] | $R_{p0,2}$ [MPa] |
| tube - **T** | | 599 | 454 | 25.7 | 189 | 247 | 368 |
| bend - „**1**” | straight zone - 1**s** | 506 | 346 | 34.3 | 158 | 223 | 222 |
| | tensioned zone - 1**e** | 511 | 348 | 34.8 | 151 | 128 | 216 |
| | compressed zone - 1**c** | 518 | 339 | 33.1 | 153 | 239 | 214 |
| bend - „**2**” | straight zone - 2**s** | 548 | 379 | 28.4 | 163 | 225 | 273 |
| | tensioned zone - 2**e** | 535 | 365 | 33.0 | 161 | 179 | 254 |
| | compressed zone - 2**c** | 537 | 351 | 33.1 | 160 | 212 | 225 |
| Requirements as per PN-EN10216-2 | | 480÷630 | >280 | >22 | 150÷197 | >27 | >180 |

The basic mechanical properties of the tube and the bends were assessed on the grounds of results of the static tension, hardness and impact tests. Tests of mechanical properties were conducted by means of the MTS-810 servo-hydraulic testing machine at room temperature and at 500 °C using cylindrical threaded (M16) samples with the diameter of $d_o$ = 10 mm. The test results thus obtained have been summarised in **Table 3**.

Material creep tests were performed at the temperature of 500 °C and the tension of 250 MPa using the ATS-2330 machine, as specified in the ASTM-E-139 standard. The creep tests consisted in simulation of deterioration of the pipeline material, i.e. the 10CrMo9-10 steel, under pre-set operating conditions of a power unit. The results thus obtained have been summarised in **Figure 6** and in **Table 4**.

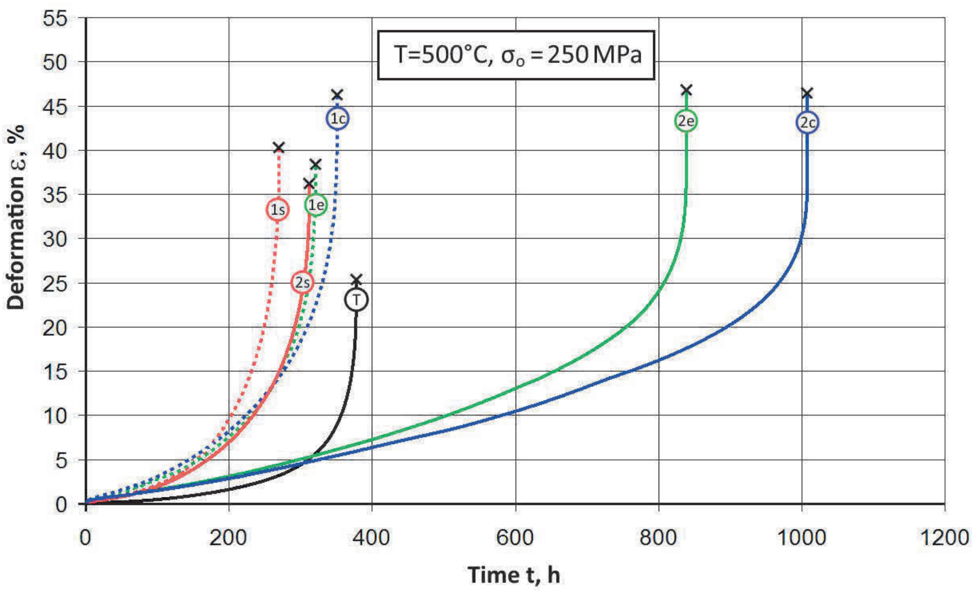


**Figure 6** Creep characteristics of material of the as-delivered tube and tube bends

**Table 4** Creep lifetime of the as-delivered tube and tube bends

| Material | tube - **T** | bend - „1” | | | bend - „2” | | |
|---|---|---|---|---|---|---|---|
| | | straight zone - 1**s** | tensioned zone - 1**e** | compressed zone - 1**c** | straight zone - 2**s** | tensioned zone - 2**e** | compressed zone - 2**c** |
| Creep lifetime $t_z$ [h] | 378 | 271 | 321 | 352 | 313 | 839 | 1008 |

## 4. RESULTS ANALYSIS

Having analysed the microstructure test results and the basic mechanical properties, one could establish that the mechanical properties ($R_m$, $R_e$, $R_{p0,2}$, HV10, KV) of the as-delivered tube material characterised by the bainitic structure were superior compared to the tube bends having a more fine-grained ferritic-bainitic structure. However, by comparing the mechanical properties of the tube bends only, one can establish that bend „2”, heat treated at lower parameters (see **Table 2**) leading to formation of a more fine-grained microstructure, is characterised by better mechanical properties. At the same time, it can be verified that the material of the tube bends made of the 10CrMo9-10 steel conforms with the requirements defined in the PN-EN 10216-2 standard.

An analysis of the results implies that the highest creep lifetime value of ($t_z$) represented by the time until the sample failure was characteristic of the material of deformed (compressed and tensioned) zones in tube bend

„2” having the finest grain in the microstructure. Service life of the same zones in tube bend „1” was considerably lower. Having compared the creep characteristics of the bends' deformed zones only, one may conclude that the factor which determined their service life was grain size. The microstructure of the tensioned zone in tube bend „2” characterised by finer grain ($\bar{A}$ = 70 μm$^2$) showed higher strain hardening of material, lower creep rate and, at the same time, increased service life (**Figure 5**). In this case, the increased strain hardening resulted from the edge dislocation slip being blocked in more numerous grain boundaries in the microstructure of tube bend „2”. The changes occurring in the material substructure in tube bends „1” and „2” due to the process of bending and the following heat treatment, being the aspect which were not studied, may have probably also exerted influence on the diversification of service life of individual zones in tube bends.

The tests conducted under the research proved that values of the material service life ($t_z$) in the tube bends' straight zones were similar (**Figure 6**, **Table 4**), yet lower (by ca. 22% on average) than that of the as-delivered tube. Bearing the foregoing in mind, one may assume that the material service life diversification observed resulted from the diversification of microstructures (ferritic-bainitic in tube bends „1” and „2”, and bainitic in the tube) as well as undoubtedly also of their substructure which, however, was not the subject of the study. For it should be noted that the straight zone of tube bends was not bent at high temperatures, and that the heat treatment of the tube bends was in fact, compared to the material of the tube being a product of thermoplastic forming, a secondary thermal procedure.

## 5. CONCLUSIONS

1) The technological process of manufacture of tube bends made of the 10CrMo9-10 steel, with the diameter of ∅508 x 20 and R = 762 mm, using induction heating and on diversified heat treatment parameters triggered changes to the microstructure and mechanical properties of the bends compared to the as-delivered tube material. The tube bends featured a fine-grained ferritic-bainitic microstructure, whereas that of the tube was bainitic. The consequence of foregoing was inferior mechanical properties ($R_m$, $R_e$, KV, HV10) of the tube bends compared to the tube material.
2) The mechanical properties ($R_m$, $R_e$, KV, HV10) of tube bend „1” subject to heat treatment with the following parameters: normalising at 940 °C / 20 min and tempering at 740 °C / 30 min were inferior to those of tube bend „2” heat treated with the following parameters: normalising at 920 °C / 20 min and tempering at 720 °C / 20 min. At the same time, the tube bend material conformed with the requirements laid down in standards PN-EN10216-2 and PN-EN12952 for both geometric features and basic mechanical properties.
3) The creep lifetime of deformed zones in tube bend „2” was significantly higher (more than twice) than that of the as-delivered tube material as well as of deformed zones in tube bend „1”.

## ACKNOWLEDGEMENTS

***The research was carried out within the task 1 of the project "The development of innovative technology for production of significantly improved bends of thick-walled steam pipelines" POIG.01.04.00-24-040/12, co-financed from the European Regional Development Fund within the Operational Programme.***

## REFERENCES

[1] Standard PN-EN 10216-2: Seamless steel tubes for pressure purposes. Technical delivery conditions. Non-alloy and alloy steel tubes with specified elevated temperature properties, *Polish Committee for Standardization*, 2009 (in polish).

[2] Standard PN-79 M-34033: Steam and water piping: Pipes wall thickness calculations, *Alfa Standard Publishing*, 1988 (in polish).

[3] CIEŚLA, M., JUNAK, G., TOMCZAK, J., FINDZIŃSKI, R., KAWAŁA, T. Durability of X10CrMoVNb9-1 steel tubes under low-cycle fatigue and creep conditions after bending with local induction heating, *Archives of Metallurgy and Materials*, 2015, vol. 60, is. 3A, pp. 1839-1845.

[4] CIEŚLA, M., MUTWIL, K., JUNAK, G. Low cycle fatigue life and creep life od material in tube bends made of 15NiCuMoNb5-6-4 steel. *In Fatigue Failure and Frecture Mechanics, XXVI Polish National Conference on Fatigue Failure and Frachture Mechanics*, 2016, pp. 020001-1 - 020001-8

[5] FARZIN, M., AHMADI, F. Finite element simulation of induction bending of large diameter pipes with a small bending radius, *Steel Research International. In International conference on metal forming; Metal forming*, 2008, pp.179-185.

[6] HU, Z., LI, J.Q. Computer simulation of pipe-bending processes with small bending radius using local induction heating; *Journal of Materials Processing Technology*. 1999, no. 91, pp. 75-79.

[7] KUBIŃSKI, W., KUCZERA, M.Gięcie rur metalowych na gorąco. *Obróbka Plastyczna Metali*, 2004, no. 4, pp 23-36 (in polish).

[8] KUBIŃSKI W. Wytwarzanie kolan rurowych na gorąco. *Metallurgy - Metallurgical Engineering News*, 2001, no. 12, pp 467-471 (in polish).

[9] REŚ, A. Metoda konwencjonalna produkcji rurociągów, a metoda gięcia w systemie 3D - porównanie i wynikające korzyści. In *1st Conference ZRE Katowice „Doświadczenie i innowacyjność - odpowiedź na zmieniające się kierunki remontów i modernizacji w Energetyce"*, 2014, Conference materials (in polish).

[10] SZALA, J. Zastosowanie metod komputerowej analizy obrazu do ilościowej oceny struktury materiałów, *Publishing House of the Silesian University of Technology*, 2002. (in polish).