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STUDY ON SELECTED MECHANICAL PROPERTIES OF SAMPLES OF MATERIAL TAKEN FROM MASS PRODUCED PIPE ELBOWS

Key words

Strength tests, mechanical property tests, mechanical properties, static tensle strength.

Abstract

The article presents the tests on selected mechanical properties of a material in form of samples taken from mass produced pipe elbows manufactured by means of bending techniques and hydroforming, using high inner pressure, and hydro calibration. The author gives a definition of the parameters and describes the static tensile stress, which according to the PN-EN ISO 6892-:2009 standard is employed for their determination. Additionally, the sampling process is presented and the research instrumentation used is characterised, i.e. the testing machine and its software. Moreover, the author shows how input parameters are set to enable the calculation, edition and acquisition of results. The results of the static tensile stress test are presented in form of graphs and tables delineating the measured values.

Introduction

A static tensile stress test conducted at the ambient temperature is a basic strength test used to evaluate mechanical properties of metals and their alloys. It enables the comparison and classification of metal materials and the verification of the success of the applied technological processes, particularly as far as thermal and plastic processing are concerned [1]. The currently biding standard on metal tensile stress tests is the PN-EN ISO 6892-:2009 test entitled "Metallic materials – Tensile testing – . Part 1: Method of test at room temperature". According to this standard, the test can be used to determine the mechanical properties of pipes and their elements like elbows, joints, sleeves, etc. which are used in the construction of different installations. Those pipes and elements that are made of stainless steel have been widely applied in many industry branches, e.g. construction, chemical industry, food industry, or energy industry, to name a few, and they prove to be very important in difficult, sometimes even extreme conditions. This is particularly crucial from the point of view of the operational safety of many objects and installations in which practically all elements have to be made of alloyed stainless steel. A specific end user of such devices is the energy sector. Most energy worldwide comes from the combustion of coal, oil, gas or nuclear power stations. The determination of the stainless steel to be used in such systems requires vast knowledge and plenty of experience. In fact, the types of stainless steel most commonly used in this industry sector are high-alloy steels, which due to their mechanical properties are particularly useful in the production of plastically processed elements [2]. However, the requirements the technologies of their processing into commercially available elements need to meet are very high. Due to the growing area of application and the increasing demands, new methods and research instrumentation are developed to enable the monitoring over the material fatigue process employing optical inspection techniques [3, 4, 5] and the high-temperature creep [6].

Currently, it is estimated that building a modern plant for the main industry sectors requires several thousand tons of stainless steel, and a large part of this is in the form of pipes and their elements [7]. These elements are supplied to thousands of users and they are generally assembled in special systems for the transmission of different media in particularly heavy loaded areas that are therefore far more prone to failure. For that reason, mass-produced pipe elbows made of stainless steel and manufactured using the advanced technologies are products that call for a thorough control at each stage of their life. A basic and standardised method for the control of mechanical properties of a material in a final product is the tensile stress test at room temperature, whose methodology is described in detail in the PN-EN ISO 6892-:2009 standard.

The Institute for Sustainable Technologies – National Research Institute conducts investigations on selected mechanical properties of metal samples from the mass produced pipe elbows. The tests have been commissioned by the international manufacturer of such elements.

1. Definitions and determination of selected properties

A static tensile stress test consists in the elongation of samples with the shape defined by the standard until they break. The tests are performed with a predetermined rate of the stress growth. The samples are mounted axially in the grips of the testing machine. At the time of the tests the value of the tensile force and stresses in recorded as a function of sample elongation. The recorded values are transferred onto the coordinate system and they form a “tensile strength chart.”

The author gives the definitions of the parameters determined during the test and the values necessary for their determination complying with the PN-EN ISO 6892-:2009 standard, and additionally presents them in the static tensile stress graph, as shown in Fig. 1.

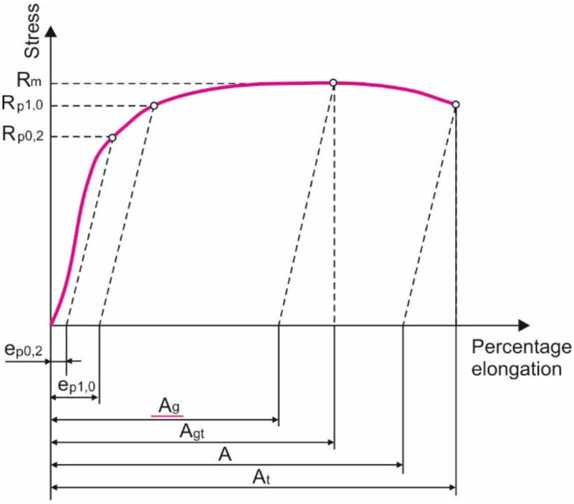

Fig. 1. Static tensile stress graph with no clear yield strength

- The initial thickness of the sample a_0;
- The initial width o the sample b_0;
- The inner diameter of the elbow opening D_0;
- The required % extensometric plastic elongation e_p;
- The elongation ΔL – increase in the initial length L_0 after the test (the break) expressed as $\Delta L = L_u - L_0$, where L_0 – initial measured length of the sample

before the application of force L_u – measured length after the break of the sample;
- The % elongation – elongation of the initial measured length L_0 in %;
- The permanent elongation after the break A – permanent elongation of the measured length after break $L_u - L_0$, expressed in % of the initial measured length L_0:

$$A = \frac{L_u - L_0}{L_0} \times 100\% \tag{1}$$

- The total % elongation at the time of the break A_t – total elongation (elastic and plastic elongation) at the time of the break expressed in % of the measured length L_0;
- The % elongation for the greatest force (A_{gr}) – increase in the measured length of the sample at the greatest force, expressed in % of the initial measured length L_0, wherein in this range the following can be observed: the total % elongation at the greatest force A_{gt} and the disproportionate % elongation at the greatest force A_g;
- The % contraction Z – the greatest change in the cross-sectional area ($S_0 - S_u$), taking place during the tests, expressed in % of the initial cross-sectional area S_0, whereas S_u refers to the smallest cross-sectional area after the break of the sample:

$$Z = \frac{S_0 - S_u}{S_0} \times 100\% \tag{2}$$

- The greatest force F_m – the greatest force in the sample at the time of tests after exceeding the yield strength;
- The tensile strength R_m – the tension corresponding to the greatest force F_m;
- The yield strength during the disproportionate increase (a conventional yield strength, yield of elasticity) R_p – tension defined for the required % plastic extensiometric elongation e_p – the value symbol is supplemented with an index determining the conventional % increase in the measured length of the extensometer, e.g. $R_{p0,2}$.

2. Test samples

Depending on the type of the tests, the samples need to be properly selected and prepared to guarantee that the results are free from interferences or external influences stemming from the presence of additional unfavourable phenomena [8].

Fig. 2 presents mass produced pipe elbows made of the 1.4571 stainless steel and obtained by means of a bending technique, hydroforming using high inner pressure, or hydro calibration.

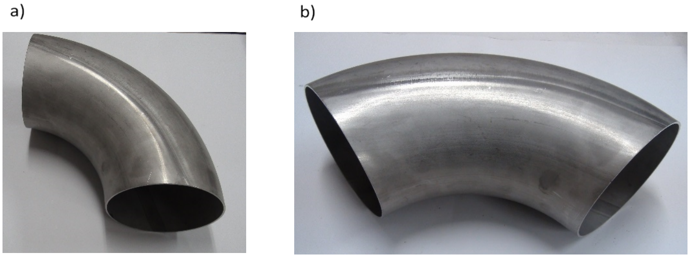

Fig. 2. Elbows made according to the EN 10253 standard: a) elbow type EN 10253-90-3-139,7×2,0-W-1.4571; b) elbow type EN 10253-90-3-169,7×2,0-W-1.4571

The shape and size of the samples, particularly of their measured parts, were selected in compliance with Appendix B containing guidelines on the dimensions (Table B.1 – Dimensions of samples) and the tolerance in the initial width of the measured parts (Table B.2 – Tolerance in the width o the test element).

Due to the shape of the object, the author excluded the possibility of direct tests, e.g. the expanding method [9, 10] or the tests performed in real thermal conditions [11]. It was found that the samples should be paddle-shaped, which would enable the execution of the static tensile strength test in the laboratory environment.

The specimens were sampled from the axial areas of the elbows with the maximum radius, first in the form of 22.5 mm wide patches milled with metal slitting saw from the elbows fixed in a suitable device mounted on the router table. The way the patches were milled is presented in Fig. 3.

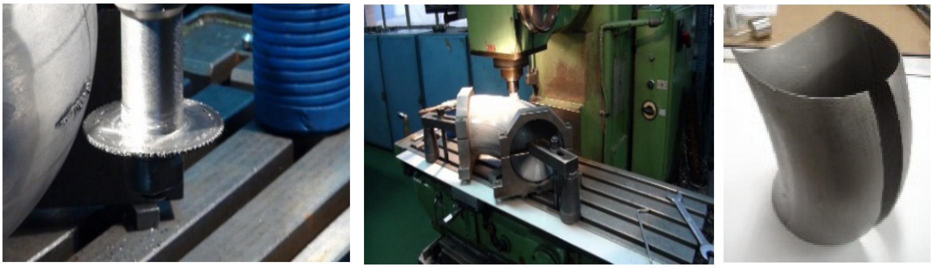

Fig. 3. Sampling of patches from pipe elbows

In the sampled patches fixed in a special grip, the sample measurement areas were also cut using the “half-side milling cutter”. The value of the tolerance in the initial width of the sample was maintained at the level advised by the standard. Fig. 4 depicts the way the sample measurement area was obtained from the elbow pipes.

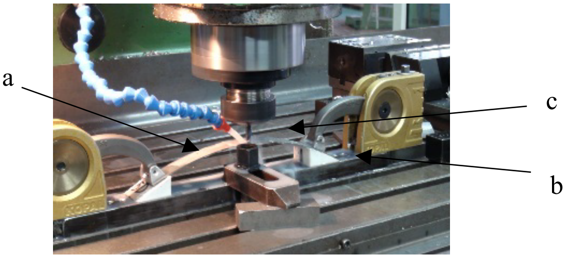

Fig. 4. Preparation of the sample measurement area: a) sample patch; b) grip; c) end mill

In order to determine the permanent elongation after the break A, the measurement lines were drawn on the measurement area (see Fig. 3) that divided the initial measured length L_0 into ten even parts. This was performed according to Appendix H to the standard in question [12]. The gripping parts of the samples were flattened, which significantly facilitated their proper assembly in the grips of the testing machine. Fig. 5 presents the samples taken from the elbows on which the measurement lines are drawn and whose ends are flattened into convenient gripping parts.

Fig. 5. Test samples a) after milling, b) after tracking, c) with flattened ends

3. Test stand

The static tensile strength test was performed on the Instron 5582 testing machine equipped with the dedicated control software, which is responsible for the setting of the test conditions, as defined by the standard, or in point 10 of the PN-EN ISO 6892-1 standard, and collects and processes data at the time of the test. The data is then presented as a tensile strength graph and tables with test results. The Bluehill 3® software and its interface and the package of modules for metal tests guarantee total control over the test parameters complying with the requirements of the ISO 6892-1 and other standards concerning tensile stress tests on elements made of steel [13]. The machine is equipped with manual wedge grips with clamping pads for flat samples, and its control room has a sample protection function that monitors the force acting on the sample during mounting, and additionally controls the device in such a way that no excessive force is applied. In conjunction with the force measurement system reset function, the system compensates the influence of the weight of the grips and the force with which the samples are mounted.

4. Tests and their results

The test consists in loading the sample mounted in the jaws of the machine and measuring the loading force and the displacement of its crossbar. The tensile stress graph is generated on regular basis from the file with the recorded data and presented on the coordinate system: tensile force – sample elongation. Based on the data file or after the test is finished, values R_{p02}, $R_{p1,0}$ and R_m are defined in the characteristic points of the graph. Such values like A and Z are calculated based on the measurements of samples before and after the test, and the provisions of the PN-EN 6892-1 standard are applied. The values of conventional values $R_{p0,2}$ and $R_{p1,0}$ are determined from the tension – increase graph by a straight line parallel to the straight part of the strain-stress curve at a distance corresponding to the % of the disproportionate increase, e.g. 0.2%. The ordinate of the point of intersection of the straight line parallel to the strain-stress curve determines the yield strength at the disproportionate increase.

An important parameter of the test is the speed at which the material is elongated. This value is controlled in the test based on the estimated speed of deformation in the length of the sample's parallel part. The speed is set through the control over the movement of the cross-bar of the machine at the speed equal to the product of the set deformation speed and the length of the parallel measurement area of the sample. For the tested samples the author assumed the following movement velocities of the machine's cross-bar: 0.3 mm/min for $R_{p0,2}$ and $R_{p1,0}$, and 0.5 mm/min for R_m, A_{50} and Z.

Before the test, the samples are subjected to a dimensional inspection, during which the initial thickness and width (respectively a_0 and b_0) are measured. The average values of these quantities, introduced into the test parameters, are used to determine the initial cross-sectional area of samples (S_0), and the value of tensions defined as a ratio of the force acting on the sample at any time of the test, to the initial sample cross-sectional area S_0.

For each sample, after its break, the material elasticity parameters were determined according to the standard (i.e. A_{50} and Z). The permanent elongation after the break A_{50} (the index refers to the initial measured length) was determined following the recommendations in point 20.1 of the standard [12] and Appendix H. The measurement of the appropriate quantities was conducted after thorough axial folding of each sample with the accuracy up to 0.1 mm, and the values of these quantities are presented in Table 1.

Table 1. Comparison of sample parameters before and after the break

Sample number	Initial gauge length of a test piece [mm]	Section of a sample operational part	Number of sections between X i Y	N-n	Value (N-n) odd					Percentage elongation after fracture A_{50}=[(XY+YZ`+YZ`` -Lo)/Lo]100%	Value (N-n) even			Percentage elongation after fracture A_{50}=[(XY+2XY-Lo)/Lo]x100%
					(N-n-1)/2	(N-n+1)/2	XY	YZ`	YZ``		(N-n)/2	XY	YZ	
	L_0	N	n							A_{50}				A_{50}
169.7/1	50.00	10	9	1	0	1	59.55	0	6.11	31.32				29.26
169.7/2	50.00	10	7	3	1	2	47.64	5.95	11.87	30.92				
169.7/3	50.00	10	5	5	2	3	34.95	12.23	18.46	31.28				
169.7/4	50.00	10	4	6	-	-	-	-	-	-	3	28.51	18.06	
139.7/1	50.00	10	7	3	1	2	48.04	6.17	12.26	32.94				
139.7/2	50.00	10	7	3	1	2	48.82	6.40	12.68	35.80				
139.7/3	50.00	10	7	3	1	2	48.60	6.20	12.46	34.52				

The % contraction Z was determined based on the measured initial parameters of the cross-section of the sample, i.e. the initial thickness a_0, the initial width b_0, and the parameters of the cross-section after the break, i.e. the thickness of the cross-section a_u and the width b_u.

The measurement of these quantities was taken with a workshop microscope and then it was averaged. The values of these quantities and the parameters determined on their basis are presented in Table 2.

Table 2. Comparison of parameters of a sample before and after the break

Sample number	$a_{0śr}$ [mm]	$b_{0śr}$ [mm]	$S_0 = a_{0śr}$ x $b_{0śr}$ [mm^2]	$a_{uśr}$ [mm]	$b_{uś®}$ [mm]	$S_u = a_{uśr}$ x $b_{uśr}$ [mm^2]	$Z = (\frac{S_0 - S_u}{S_0}) \times 100\%$
169.7/1	1.60	12.45	19.92	0.87	9.81	8.53	57.16
169.7/2	1.65	12.45	20.54	0.76	9.55	7.26	64.67
169.7/3	1.61	12.46	20.06	0.99	9.25	9.16	54.35
169.7/4	1.63	12.50	20.38	0.84	9.30	7.81	61.66
139.7/1	1.55	12.48	19.34	0.65	9.28	6.03	68.82
139.7/2	1.58	12.50	19.75	0.86	9.05	7.78	60.59
139.7/3	1.58	12.49	19.73	0.89	9.27	8.25	58.19

As a result of the tests carried out, a summary tensile strength graph and the values Rp_{02}, $Rp_{1,0}$ and Rm were obtained. Fig. 6 presents the tensile strength graphs for samples taken from pipe elbows with a diameter of 139.7 mm and 169.7 mm.

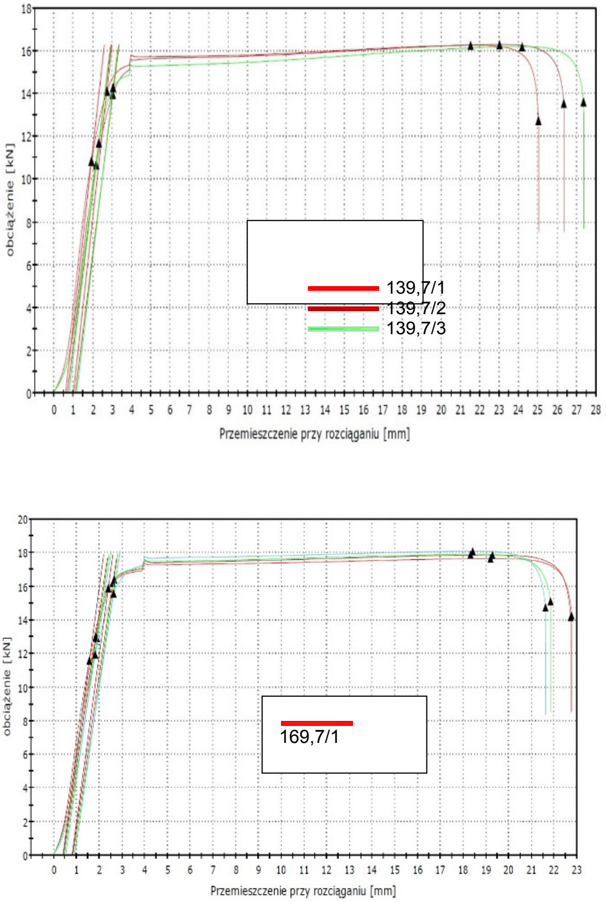

Fig. 6. Graphs of the static tensile strength test for samples taken from pipe elbows

The determined values of mechanical properties R_{p02}, $R_{p1,0}$, R_m, A_{50} and Z for samples taken from elbows EN 10253-90-3-139,7×2,0-W-1.4571 are presented in Table 3, and the ones determined for samples taken from pipe elbows EN 10253-90-3-169,7×2,0-W-1.4571 are shown in Table 4.

Table 3. Comparison of values R_{p02}, $R_{p1,0}$, R_m, A_{50} and Z from samples taken from pipe elbows EN 10253-90-3-139,7×2,0-W-1.4571

	Sample label	F_{max} [kN]	$R_{p0,2}$ [MPa]	R_{p1} [MPa]	Tension at F_{max} R_m [MPa]	% contraction of the cross-section Z_{50} [%]	% elongation after the break A [%]
1	139,7/1	16,3	561,31	729,73	840,62	68,82	32,94
2	139,7/2	16,3	541,27	707,32	824,91	60,59	35,80
3	139,7/3	16,2	562,87	723,92	820,62	58,19	34,52
Maximum		16,3	562,87	729,73	840,62	68,82	35,80
Minimum		16,2	541,27	707,32	820,62	58,19	32,94
Average		16,2	552,07	720,32	828,72	62,53	34,42
Standard deflection		0,05	12,05	11,62	10,52	5,57	1,43

Table 4. Comparison of values R_{p02}, $R_{p1,0}$, R_m, A_{50} and Z from samples taken from pipe elbows EN 10253-90-3-169,7×2,0-W-1.4571

	Sample label	F_{max} [kN]	$R_{p0,2}$ [MPa]	R_{p1} [MPa]	Tension at F_{max} R_m [MPa]	% contraction of the cross-section Z_{50} [%]	% elongation after the break A [%]
1	169,7/1	17,6	520,02	647,42	705,97	57,16	31,32
2	169,7/2	17,9	503,23	635,02	714,36	54,67	30,92
3	169,7/3	17,9	516,98	655,85	715,52	54,35	31,28
4*	169,7/4	18,1	586,1	764,22	887,32	61,66	29,26
Maximum		17,9	520,02	655,85	715,52	58,72	31,32
Minimum		17,6	503,23	635,02	705,97	54,35	30,92
Average		17,8	513,41	646,09	711,95	55,39	31,17
Standard deflection		0,17	8,95	10,48	5,21	1,54	0,22

* sample excluded from tests

Due to the values of the determined parameters that significantly differed from all the other parameters, Sample 4 with the label 169,7/4 taken from elbow 4- EN 10253-90-3-169,7×2,0-W-1.4571 from the patch asymmetric to the axis of the product, was excluded from the tests.

The 1.4571 steel is an austenitic stainless steel which according to different sources [14] is characterised by the following minimum mechanical properties: resistance to elongation $R_m = 520 – 670$ MPa, conventional yield strength $R_{p0,2} =$ $= 220$ MPa and $R_{p1,0} = 260$ MPa and elongation A = 40%.

Summary

A tensile strength test is a basic and at the same time indispensable strength test in the control over the quality of goods made of stainless steel type 1.4571.

The mechanical properties of this steel, higher than these given by selected sources, e.g. $R_{p0,2}$, $R_{p1,0}$ and R_m result from the manufacture technologies and processes employed, particularly the processes of preliminary bending and hydroforming of their final shapes. As a result of cold plastic processing, the mechanical properties of austenitic stainless steel reach higher values. This is followed by the so-called strengthening through squeeze that reduces the ductility parameters like A and Z.

The asymmetry of areas from which the samples were taken with reference to the axis of the elbows has an influence on the result of the determined properties and limits the possibility to compare the results. The use of a suitable sampling technique, instrumentation, and tools significantly reduces the risk of an error.

The determination of the elongation of the sample with no measurements and calculations vitiated by an error, and its control at the time of the tensile strength test until the sample breaks, should be performed using extensometers with a varied measurement base and automatic grips.

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Badania wybranych właściwości wytrzymałościowych próbek materiału pobieranych z produkowanych seryjnie kolan rurowych

Słowa kluczowe

Badania wytrzymałościowe materiałów, badania własności mechanicznych, własności mechaniczne materiałów, statyczna próba rozciągania.

Streszczenie

W artykule przedstawiono badania wybranych właściwości wytrzymałościowych materiału w postaci próbek pobranych z produkowanych seryjnie kolan rurowych wytwarzanych z rur techniką gięcia oraz technologiami hydroformowania poprzez formowanie wysokim ciśnieniem wewnętrznym i hydrokalibrowanie. Podano definicje wyznaczanych parametrów oraz opisano statyczną próbę rozciągania służącą w świetle normy PN-EN ISO 6892-:2009 ich wyznaczeniu. Omówiono sposób pobierania próbek z gotowego wyrobu i przygotowania ich do badań. Scharakteryzowano instrumentarium do pomiarów próbek, maszynę wytrzymałościową wraz z oprogramowaniem oraz pokazano wprowadzanie najważniejszych parametrów wejściowych służących obliczeniom oraz edycji i akwizycji wyników. Omówiono i skomentowano wyniki statycznej próby rozciągania przedstawione w postaci wykresów oraz wyznaczanych wielkości podanych w formie tabel.