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INSTITUTE OF INFORMATION AND COMMUNICATION TECHNOLOGIES

Abstract of PhD Thesis

INNOVATIVE METHODS FOR TECHNOLOGICAL DIAGNOSTICS OF AUTOMATIC MACHINES AND LINES

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The results included in the dissertation were presented and discussed at an extended session of the Department of Embedded Intelligent Technologies, IICT-BAS, on January 18, 2022. It was decided that dissertation defense should take place.

The dissertation contains 153 pages, including figures, tables and a bibliography containing 163 titles. An application has been added.

The Defense of the PhD thesis had been held on ………., 2022 at office room of IICT-BAS, Block 2.

Keywords: *technological diagnostics, test pieces, tensile strength, spectral analysis, tomography .*

Introduction

Technological diagnostics covers issues of search and automated fault control. It is related to the development of innovative methods and tools for monitoring and control, creation of diagnostic tests, active testing, embedded diagnostic systems, assessment of the ability of the control and diagnostic system.

The need to establish the factory is presented; Bulgarian and world producers of metal and pipes; hardware methods and means for intelligent measurement and analysis of machine performance maintenance.

An innovative approach to the operation of technological equipment is presented; the standards and brands of steels are presented, as well as the produced types of pipes and profiles; The innovative procedures for quality control in the production of thin-walled electric welded pipes and profiles, as well as the defects that occur in the production process are analyzed.

Methodologies have been developed to use the necessary devices; attention is paid to the main functions influencing the measurements. On the basis of the compiled methods the preparation of a test body for testing with spectral analysis, tensile strength in low-carbon steel and the production of high-strength steel is carried out; measurement of roughness and hardness, as well as the measurement of geometric characteristics and the measurement of geometric characteristics with a 3D computer tomograph.

The results achieved by research and production research are presented. An analysis of the chemical and mechanical parameters of low-carbon metal during its transformation from hot-rolled metal to cold-rolled metal, results of high-strength steel production, as well as analysis of measured parameters carried out during the technological process.

The future projects for the development of the factory for the production of pipes and profiles are presented.

Aim and tasks of the thesis

The submitted dissertation deals with problems related to the technological diagnostics of automatic machines and lines. The aim of the thesis is to study the progress and integration of new technologies in modern diagnostics of automatic machines and lines and to propose an innovative approach to creating test methods.

To achieve this aim, the following tasks will be solved:

1. After a detailed review to analyze and systematize approaches and methods for integrating intelligent technologies in technical diagnostic procedures.
2. To study existing methods and tools for modern diagnostics of automatic machines and lines.

3. To study the impact of ICT on technical diagnostic methods.
4. To propose and substantiate innovative methodologies for types of diagnostics of automatic machines and lines.
5. To conduct experiments and simulations of different methods in industrial environments.
6. The obtained results should be analyzed and tested.

Chapter 1

OVERVIEW, ANALYSIS AND SYSTEMATIZATION OF METHODS AND TOOLS FOR TECHNOLOGICAL DIAGNOSTICS OF AUTOMATIC MACHINES AND LINES

1.1. Historical background

The development of science and the implementation of innovations enabled in 1995 the establishment of FPTFK (Factory for the production of tubular furniture and components), together with the company "IKEA" - Sweden. It was agreed to jointly realize the production of components from parts, assemblies and installation of modern and luxury metal furniture.

Over time, in order to improve working conditions, there is a need to organize their own production of thin-walled electric welded profiles and cold-rolled steel (CRS) pipes.

Encouraged by the closure of the entire production cycle and the removal of the influence of external distributors, suppliers of finished profiles, the joint management decided to establish and organize a subsidiary FPPP (Factory for the production of pipes and profiles).

The creation of the new factory is fully in line with the trends for digital development "Industry 4.0" and implementation of the components of cyber-physical systems: intelligent machines, embedded self-regulating systems, hardware, software and more uniquely addressed objects and networks that intelligently interact with each other to achieve the set aim, [162, 163].

Manufactured products:

- Hot rolled narrow strips
- Hot rolled stained narrow strips
- Hot rolled stained precision tubes and profiles
- Cold rolled strips and coils (Fig. 1.5.)
- Cold rolled electric welded pipes and profiles (Fig. 1.3. And Fig. 1.4.)

Fig.1.3. Steel pipes

Fig.1.4. Steel profiles

Fig. 1.5. Steel coils

1.4. Hardware methods and instruments for intelligent measurement

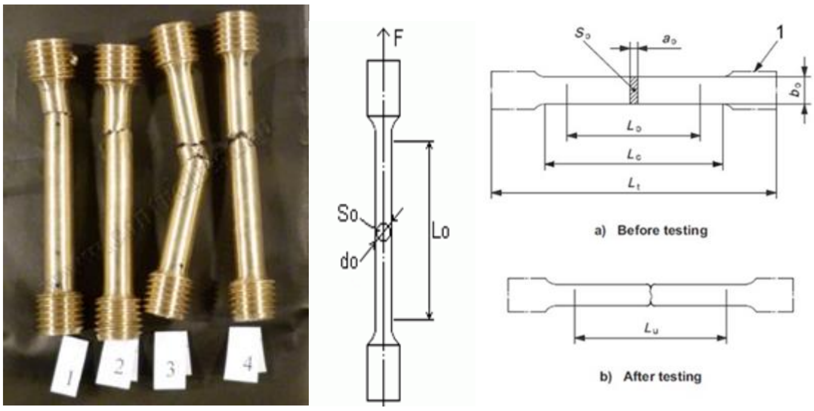
1.4.1. Types of operations and punching machines

By punching (Fig. 1.11; 1.12) metal specimens are prepared for tensile strength testing [22, 23, 24, 25]. One of the most widely used punching machines is called a press and may consist of one or more replaceable dies. Punching is done with different presses (punches), which have a complex structure.

1.4.2. Machines for testing strength, tension, compression and bending

1.4.2.1. Standard test methods

Strength tests extract information about certain mechanical properties of materials that are important for their further use in the manufacture of various parts, machines and equipment. Since tests most often end in destruction, it is normal to work with test specimens rather than finished products. In Fig. 1.13 test specimens with tensile strength are presented.



a) b)

Fig. 1.13. Tensile strength specimens: (a) tube; (b) a flat body with a rectangular cross-section

4. *Universal tensile strength machine WDW-300,* shown in fig. 1.16.

The maximum load capacity is 300 kN, and the measuring range is 1.2 kN ~ 300 kN. The accuracy of the load is ± 0.5%; The speed range is 0.005 mm / min ～ 500mm / min infinitely. Operation at an ambient temperature of 10 ~ 35 °C and relative humidity ≤ 80% [32]. The maximum tension movement is 600 mm, the maximum pressure movement - 600 mm, the width of the test area: 600 mm and the maximum movement of the slider: 1350mm;

1.4.3. Selection of spectral devices

Spectral analysis allows to create a kind of elemental analysis - atomic spectral analysis, which can quantify the content of various elements in a sample of matter by decomposing them into atoms or ions in the flame or electric arc. Spectral analysis is a set of physical methods for quantitative and qualitative determination of the composition of substances by studying their spectra. The relationship between the composition of a substance and the electromagnetic spectrum emitted or absorbed by it allows spectral analysis to be used as a sensitive, relatively easy and fast method in research, industry and other fields.

1.4.6. 3D computed tomography

The 3D scanner (computed tomography) is a non-invasive procedure that uses a special X-ray machine connected to a computer that creates multiple images of a part of the body that needs to be examined. Based on these images, the computer synthesizes a three-dimensional model of the captured structures.

3D computed tomography is widely used in the analysis of various materials. Nikon XT H 225 3D industrial computed tomography (Fig. 1.29) is used for the analysis of the linear values of width and thickness [43, 44].

Fig. 1.16. Universal tensile strength machine WDW-300

Fig. 1.29. 3D industrial computer tomograph Nikon XT H 225

Computed tomography (CT) provides high accuracy and has the ability to examine the internal and external dimensions of the provided samples (samples, blanks). In addition, it provides an additional view of the internal microstructure of the object under study, examining it for inhomogeneity.

1.5.2. Optimal performance of automatic equipment

The aim of every company is to achieve optimal machine productivity in order to achieve greater productivity and lower costs. But here are already settling: To produce better quality, increase safety, protect the environment, the need for higher morale.

The condition of the equipment (AM and AL, A of the whole technological process and operations) determines the production, quality, supply, safety and morale. The aim is to strive for optimal values.

1.6. Conclusion:

This chapter provides an overview and analysis of various producers of HR and CR metal and Bulgarian and foreign pipe manufacturers. Different types of machines for punching parts (test bodies), for testing for tensile strength, pressure and bending, spectral analysis of materials, mechanical measuring instruments and how to measure physical quantities are presented. The innovative method of analysis by computed tomography and the types of printing devices by SLA and FDM are considered. Management models of Tsikuba and INAX for analysis of maintenance and increase of machine productivity are considered.

Chapter 2

INNOVATIVE APPROACH TO TECHNOLOGIES AND TECHNOLOGICAL EQUIPMENT

To follow the innovative approach to the use, implementation and operation of technologies and technological equipment, a regulation is created, tracking the production of thin-walled electro-welded closed profiles of cold-rolled steel (CRS) [57, 58] in the ZPTP.

The approach used aims to follow step by step the implemented innovative technologies and technical equipment, realizing the particularly difficult combination of automation of continuous and discrete, basic and auxiliary processes and operations, ensuring and achieving high technical and economic performance with comprehensive control of materials , equipment, manpower, risk, environmental protection, etc.

2.1.2. Used steel grades

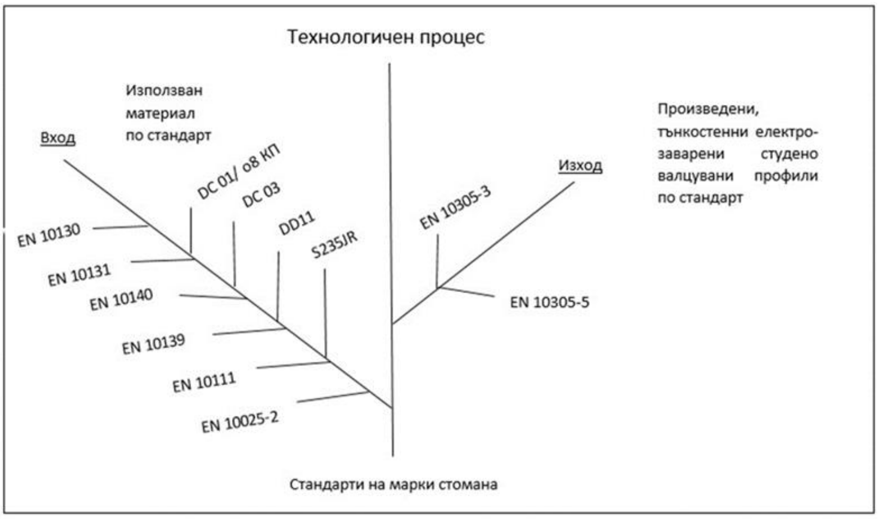


Fig. 2.1. Used steel grades and corresponding standards

In Fig. 2.1. The necessary used steels are shown, ensuring the production of profiles from thin-walled cold-rolled electro-welded steels, meeting the standards of BDS, DIN, EO, EN, IKEA.

2.2. Operation of innovative technologies and technological equipment

In Fig. 2.2. a scheme of implemented innovative technologies is shown, providing the innovative equipment for the production of thin-walled electro-welded closed profiles from CRS, providing primarily its own production of tubular furniture for external customers. Simultaneously with the monitoring of management, production, quality control step by step, the digitalization of "tight production" is being implemented.

2.4. Strip quality control approach

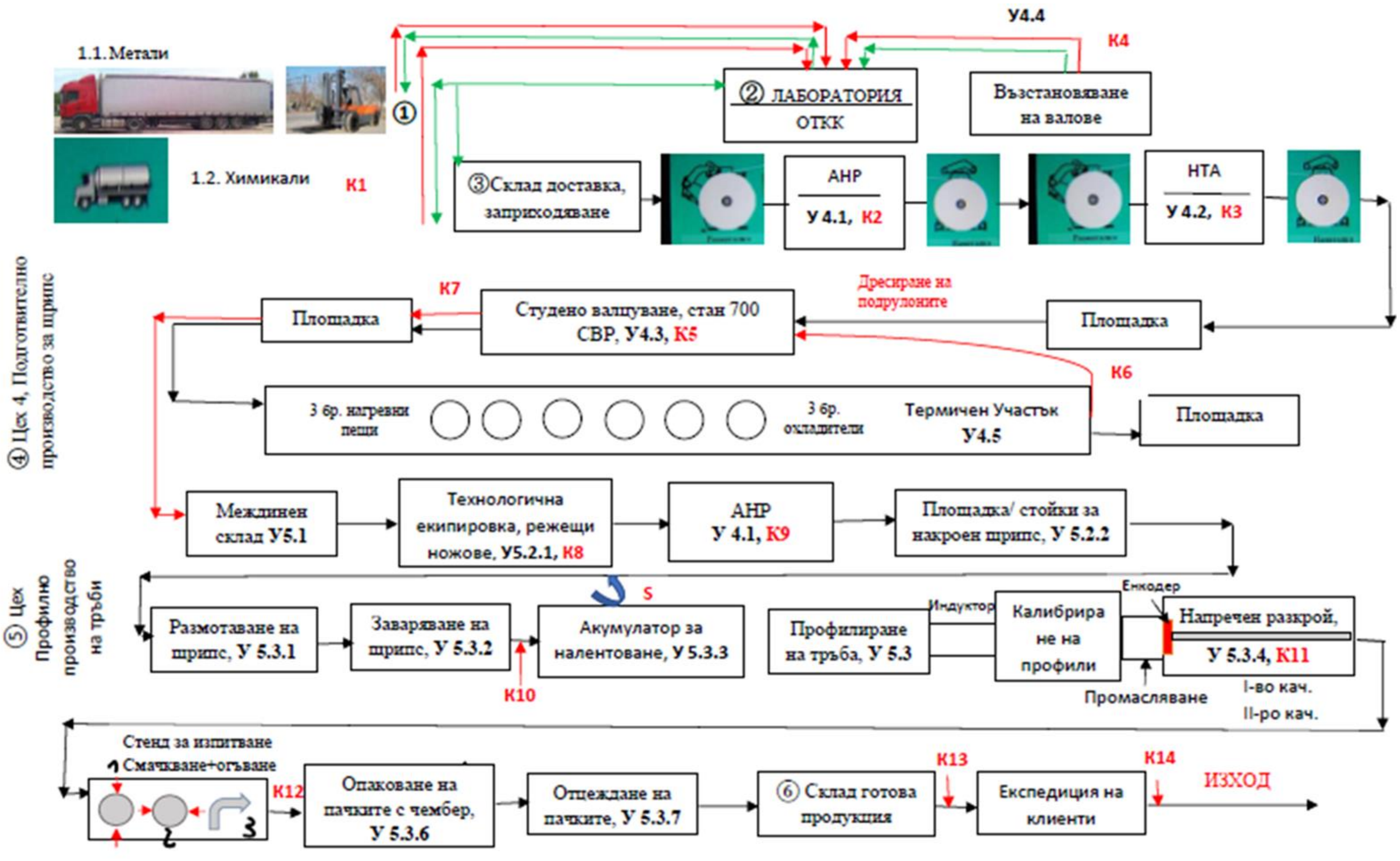
The approach consistently monitors and analyzes the operational control of the technological implementation in the production of strips from CRS or HRS. This standard strip

strip is the basis for profiling and calibration of pipes and profiles in adjustable automatic pipe lines of the product thin-walled electrowelded closed profiles.

The data is entered into the IT computer system of the server, from where each manager and interested party can monitor the status of an order - the duration and operations through which the metal has passed. A quality management system (QMS) has been established, which is to be certified according to ISO 9001. The implementation of this procedure aims to ensure the constant relevance, adequacy and efficiency of QMS, including quality policy and objectives, to ensure continuous and improvement. In order to discuss current tasks, problems, projects and developments, meetings can be held daily, weekly or monthly in the form of operatives between the various units in the Organization.

2.6. Conclusion:

Chapter 2 presents the tubes and profiles produced, the steel grades used and the corresponding standards. It is presented schematically and by describing the operation of innovative technologies and technological equipment, describing all units in the plant, as well as what is monitored for quality control: unbroken pickling unit, single-cell roller mill 700, thermal section, unit for longitudinal and transverse cutting , automatic pipe lines, lubrication station, construction department and tool production. An approach for technological realization is proposed, which covers steps of production and auxiliary processes, operations and control for quantitative and qualitative establishment, documentation and presentation of the finished products in the warehouse. The factors for quality control are described. A quality management system is being implemented through digitization of operational documents. The defects that occur from the production of steel to the production of pipes and profiles are described.



Фиг. 2.2 Схема на иновативни технологии и технологично оборудване

Chapter 3

ESTABLISHMENT OF METHODS FOR INTELLIGENT RESEARCH

The development of a methodology is extremely important for conducting research. The repeatability of the methodologies and the sequence of actions and processes ensures uniformity in the obtained results. A number of factors need to be addressed for the different studies.

For the production of thin-walled pipes from cold-rolled steel for tubular furniture and other products are used a number of technological processes and operations implemented on innovative automatic machines, automatic lines and units equipped with the necessary technological equipment and modern digital control. This requires the development of a methodology for intelligent measurement of their production, which includes 13 methodologies:

1. Method for technological preparation of a sample / test tube
2. Compilation of a method for testing a specimen (test body) for tensile strength testing
3. Development of a methodology for testing linear plastic deformation of a rigid body
4. Development of methodology and experimental study of carbon steel in tension
5. Methodology for preparation and conducting spectral analysis of a metal test body
6. Development of a methodology for monitoring the mechanical characteristics in tensile testing of test specimens of low-carbon steel during its transformation from hot-rolled to cold-rolled sheet metal
7. Development of a methodology for innovative production of high-strength cold-rolled steel for precision electric welded pipes
8. Development of a methodology for innovative measurement of the geometric characteristics of a metal test body using a 3D computer tomograph
9. Design of a new type of innovative test body holder / rectangular sample for 3D computed tomography
10. Compilation of a methodology for analyzing the characteristics of a test body before sharpening the punch
11. Compilation of a methodology for studying the hardness of working rolls on a cold rolling mill
12. Compilation of a methodology for machining and roughness of the working rolls for reversing mill for cold rolling
13. Development of a methodology for testing the roughness of low-carbon steel after cold rolling of reversible loom 700

3.14. Conclusion:

13 methodologies have been compiled to support the experiments conducted in Chapter 4. Strict adherence to the methodologies can contribute to more accurate results and intelligent research. Carrying out experiments on methodologies leads to a reduction in marriage in the production of pipes and profiles.

Chapter 4

EXPERIMENTAL RESULTS IN TECHNOLOGICAL DIAGNOSIS OF AUTOMATIC MACHINES AND LINES

4.1. TECHNOLOGICAL PREPARATION OF SAMPLE / TEST PIECES

Test pieces, also called specimen, are prepared according to standard, Part 1: Room temperature test method BDS EN ISO 6892-1.

4.1.1. Form

Typically, test specimens should have widenings at both ends of the parallel length that engage the jaws of the tensile strength machine. The other reason for these widenings is to avoid breaking the sample at the gripping area with the jaws of the test machine. The parallel length Lc must be connected to the ends of the test piece by means of transition curves with a radius of at least 20 mm. The width of these ends must be ≥1,2 b0, where b0 is the original width.

4.1.2. Test body dimensions

The dimensions of the test piece are determined from Table 4.1 and the tolerances are taken into account according to Table 4.2. In our case we have chosen a type of test body № 2 with a width of 20 ± 1 mm.

The resulting test piece has the following dimensions:

b_0- 20 mm, width of the widenings 30 mm;

L_c- 120 mm;

L_0- 80 mm;

L_t- 180 mm.

4.2. SELECTION OF TECHNICAL EQUIPMENT

4.2.1. Tensile strength testing machine

All mechanical tests of metal samples during the various stages of processing are performed with a universal electromechanical test machine WDW-300 (presented in Chapter 1). The maximum tensile load is 300kN, the load accuracy is 0.5%.

4.2.2. Spectral analysis machine

The other quality control device used is the BRUKER Q2 ION OES metal analyzer [128, 129]. The Q2 ION spectrometer performs the metal analysis in 30 seconds. Works with argon. This is a universal multi-matrix system for complete inspection and quality of the input material of metal alloys.

4.3.TEST BODY PREPARATION / PUNCHING SAMPLE

The press used for punching is hydraulic with a single simple cutting trough. The hole of the punch for placing the workpiece has dimensions HxW - 300x40 mm.

4.4. Preparation for sizing and linear plastic deformation of a metal test body

Using a micrometer, measure in three places the diameter / do / or the thickness of the test pieces along the length of the working section to the nearest 0,01 mm. The measured minimum diameter / thickness determines the cross-sectional area So. The test length lo is then applied to the working area. This delineation is made so that after its testing the elongation A80%, mm [130-136] can be calculated.

The definitions of elongation required for the analysis of a test piece are shown:

A is the percentage elongation after rupture (calculated from the extensometer or directly from the test specimen) - $A_{\%} = \frac{Lu-Lo}{Lo}x100$;

Ag is a plastic elongation at maximum force - - $Ag_{\%} = (\frac{\triangle Lm}{Le} - \frac{Rm}{mE})x100$;

Agt is the total percentage elongation at maximum force - $Agt_{\%} = \frac{\triangle Lm}{Le}x100$;

At is the total percentage elongation after total rupture;

"e" is a percentage extension; $At_{\%} = \frac{\triangle Lf}{Le}x100$;

mE is the slope of the elastic part of the stress-percentage elongation graph;

R is voltage;

Rm is tensile strength- $Rm_{\%} = \frac{Fmax}{So}x100$;

$\triangle$ e is an extension zone;

Le is the measuring range (extensometer)

Table 4.3 presents an example of calculating the elongation of a test piece at the tensile strength of a low carbon steel metal test piece.

Table 4.3. Initial, final and calculated elongation parameters of the test piece

Initial parameters		Parameters after rupture		Calculated parameters	
a, mm	20	Fm, kN	8.28	Rm, MPa	360
b, mm	1.15			A, %	32
Lo, mm	80	Lu, mm	106	At,%	31.5
So, mm	23			Agt,%	22.5
Le,mm	120	m_E,MPa	240	Ag,%	21

4.5. Experimental study of carbon steel samples at tensile strength

In order to facilitate the processing of the results are exported to an Excel file (Fig. 4.10), where they can be systematized according to the required parameters. Also directly from the program can be prepared a test report with the schedule and the desired parameters that need to appear in the report.

After the test, the data processing software calculates all of the parameters, only the relative elongation A80,% is calculated manually by measuring from the tube using a caliper.

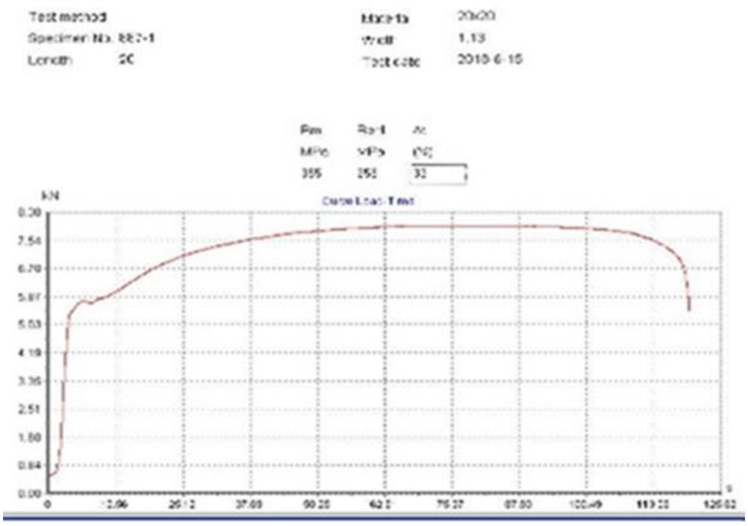


Fig. 4.11 Graph of hot rolled metal

4.6. Study of the chemical parameters of carbon steel

In order to make sure that the delivered raw material meets the parameters of the certificate, control measurements of all characteristics are made. The aim is to minimize errors in the preparation of operating modes and obtaining satisfactory values of the metal after its processing.

After the rolls are saved, the data of each roll is entered in a logbook. An analysis of samples from each roll is made and compared with the data from the certificate. In addition, a comparison is made with the data that must meet the standard for the respective steel grade.

In most cases the values of the chemical composition correspond to the values indicated in the certificate, but there are cases in which a large discrepancy occurs as shown in Table 4.6. This leads to a discrepancy in the values of mechanical parameters in higher limits, which if not complied with will have a problem in the technological process.

Table 4.6 Comparison of chemical and mechanical parameters by certificate and after test

Type	Steel grade	№ of Heat	Chemical composition				Rm (Mpa)	Re (Mpa)	A,%
			C	Mn	Si	Al			
Certificate data	DD11	915921	0,06	0,24	0,008	0,320	386	285	33
Control sample			0,08	0,26	0,012	0,033	410	335	29

4.7. Technological setting and experimental results from the transformation of the mechanical characteristics from GVR to SVR

A single-cell mill (Rolling Mill with one roll) was used for the study, and the metal used was 2 mm thick and 550 mm wide, with a roll weight of 6 t, manufactured in Romania by ArcelorMittal Galati S.A. The initial thickness after rolling is 1.13 mm, after 3 passes through the reversible rollers.

4.7.1. Heat treatment of metal

- Fe-C state diagram

➢ The methodology from the diagram in fig. 4.13 is described by the heat treatment process, which takes place in 5 stages:

1) Purge;

2) Heating the metal to 350°C for a period of 3 hours;

3) Subsequent heating of the metal from 300°C to ~ 650°C for a period of 6 hours;

4) Air cooling until the metal reaches 300°C;

5) Water cooling from 300°C to 80°C.

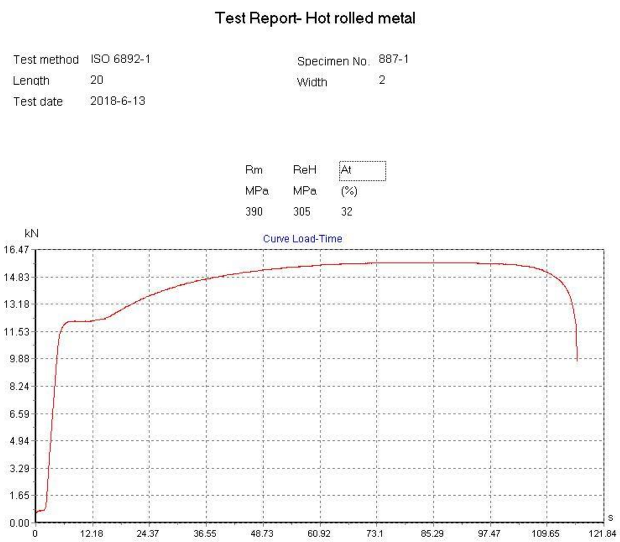
During the annealing cycle, a shielding gas flows, which is a mixture of 96% nitrogen and 4% hydrogen. The first stage (purge) is an extremely important process and an integral part of the cycle, because the purpose of the passage of this protective gas is to expel the oxygen that is in the space between the rolls. Otherwise, oxidation of the metal will occur.

4.7.2. Test results

Table 4.8 Mechanical characteristics during different stages of the technological process

Type	Rm	Re	A
	Mpa	Mpa	%
HRC	390	305	32
CRC	695	695	2.5
After annealing	355	255	33
After skin pass	365	330	25

4.7.3. Tensile strength testing diagrams



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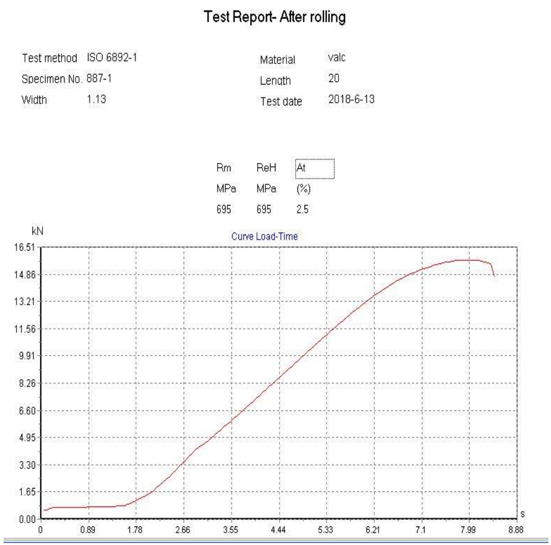

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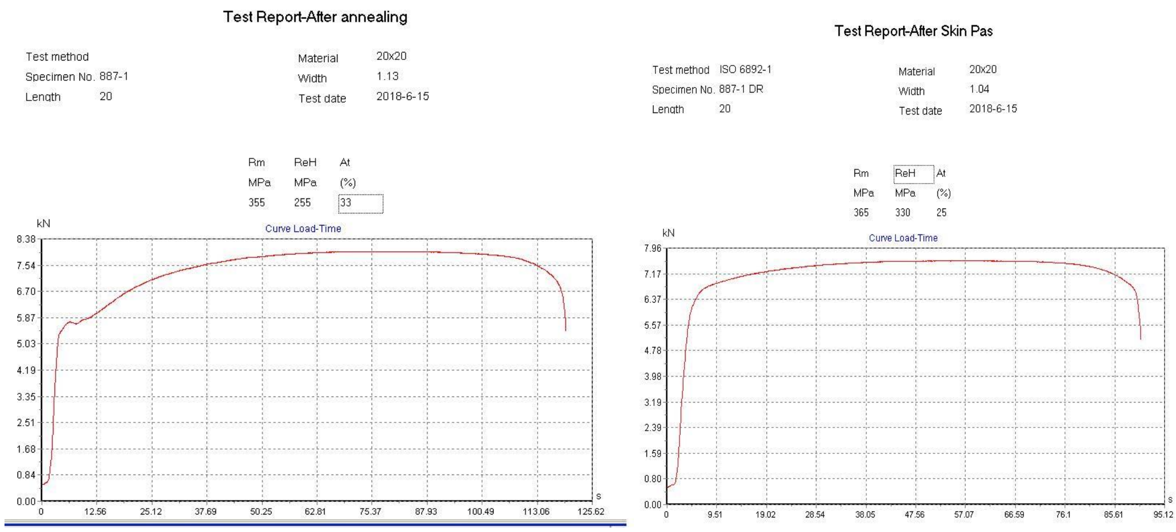

B) Г)

Fig. 4.14 Diagrams of tensile strength testing:

A) HRS, B) CRS, C) after annealing, D) after skin pass

4.8. Innovative production of high-strength steel

From the analysis of the characteristics of the steel grade S235JR (EN 1.0038 Steel), Standard EN 10025-2 it was found that it is close to the requirements of E320 and E370.

Based on the performed experimental data and analyzes, a technological regime for the production of pipes with brand E320 and E370, standard EN 10305-3 and EN 10305-5 has been developed depending on the input data of the material, chemical composition and mechanical parameters.

4.8.2. Technological regime and experimental results

After analyzing the input parameters of the HR raw material, which show that the material is suitable for the production of E320 steel, the metal is cut to the required width, stained (surface cleaning of scale, corrosion and dirt) and a rolling assignment is prepared according to the desired thickness . In our case, the desired thickness is 1.0 mm.

When rolling from 2.0 mm to 1.0 mm, the number of passes is 3:

1- 2.0 mm → 1.55 mm 22.5%
2- 1.55 mm → 1.25 mm 19.4%
3- 1.25 mm → 1.0 mm 20%

After the rolling mode, the annealing mode and% deformation during training (skin pass) are determined. The annealing process consists of several stages:

1) Purge - 1 hour (for the purpose of expelling oxygen, by means of protective gas from nitrogen and carbon)

2) 1st delay - 350ºC / 3h: Heating the metal to 350ºC for 3 hours

3) 2nd delay - 620ºC / 20 min. Per ton (polygonization): Raising the temperature to 620ºC, and the time is determined by the amount of metal in tons per hour. For example, with a stand with a tonnage of 24 tons, 8 hours are obtained.

4) Cooling with air up to 300ºC
5) Cooling with water from 300ºC ÷ 100ºC
6) Unpacking the rolls and natural cooling to 40ºC

To properly report the results after annealing, it is necessary to place three samples in different places, simulating sampling from the beginning, middle and end of the roll. The results of the 3 samples are averaged.

After the heat treatment, the rolls go through another stage - training / skin pass. Through it the metal becomes more shiny and superficially strengthened. Depending on which brand of steel we want to achieve, the percentage of deformation in training after annealing is different. Table 4.11.

Table 4.11. Percentage of deformation in different steel grades

Steel drade	% Deformation	Steel drade	% Deformation
E320	3	E275	10
E370	4,5	E355	15
E420	6		

4.9. Sharpening the punch

For proper testing of mechanical parameters, its linear dimensions (width and thickness) must be monitored and whether the punch blades do not wear out. With worn knives, there is a loss of uniformity over the entire area [144, 145].

4.9.1. Analysis of the geometrical characteristics with a micrometer and a caliper and by means of a 3D computer tomograph before sharpening the punch for cutting metal samples

When adjusting the arithmetic mean of the measured widths and thicknesses of the test body, the following parameters are obtained:

- The values of the samples measured with a micrometer and a caliper

a = 0.96 mm; b = 20.01 mm

- Sample values measured by 3D computed tomography

a = 0.99 mm; b = 20.07 mm

If we make a simulation of the tensile strength test, Table 4.14 at force F = 6,5 kN, it will be calculated by the formula Rm% = F / Sx100 and cross-sectional area S = a.b, we will get the following values:

Table 4.14: Simulation of tensile strength calculation

Measured with:	S, mm	Rm, Mpa
micrometer and caliper	19.2096	338
3D CT	19.8693	327

Figures 4.16 and 4.17 show images from the 3D computed tomography of the scanned test specimens of their thickness and width.

When the test body is cut off by punching, wear of the knife occurs during prolonged operation. This phenomenon is observed in fig. 4.18. The height of the resulting patch was measured using a 3D tomograph. After the analysis from the computed tomography it is clearly seen that on both sides of the test body, the thickness is significantly less than the real one, which is a consequence of the worn knife in punching fig. 4.16.

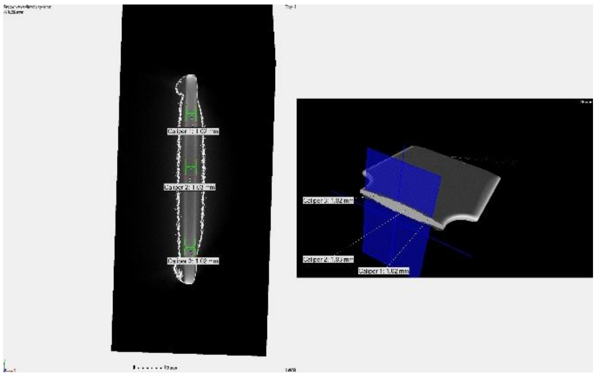

Fig. 4.16 Measured thickness with 3D tomograph; Fig.4.17 Measured width with 3D tomograph

4.9.2. Comparative analysis of the geometrical characteristics before and after sharpening of the sample cutting press

After the 3D computer analysis of the sample prepared before sharpening the guillotine knives of the press, a defect on its surface is clearly visualized. Due to the wear of the knives, the metal is crushed and deformed. The size of the defect is 0.12 mm is shown in Fig.4.19.

From the examinations of the two types of specimens it is clear that the deformed specimen produced before sharpening the knives shows deformation. . Significantly less thickness was measured at the edges of the sample than the actual thickness in the middle - 0.92 mm; 1.04 mm; 0.88 mm.

From the analysis of the sample prepared after sharpening the press, a uniform width and thickness can be noticed (Fig. 4.26). The dimensions of the width are: 19.98 mm; 19.96 mm; 19.96 mm, and those of thickness are 1.01 mm; 1.03 mm, 1.01 mm.

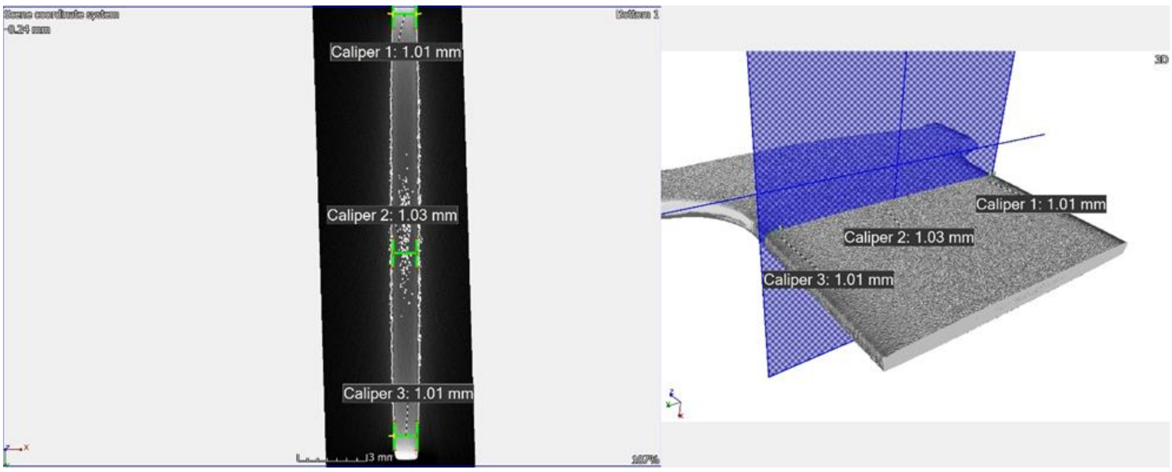

Fig.4.26. Measurement of sample thickness after sharpening

4.10. Creating a new type of innovative test holder for 3D computed tomography

The holder shown in fig. 4.28 is designed to allow the placement and attachment of several types of tubes, depending on their thickness [146].

4.10.3. 3D printed holder

The modeled holder, FIG. 4.29 is manufactured using additive technology on a 3D Fused Deposition Modeling (FDM) printer. It was chosen because its consumables are cheaper and the design of the prototype does not require great precision in printing.

4.10.4. 3D computed tomography

The utility model holder for test specimens works as follows: The test object (tube) is placed in the holder, then fixed in the support mass of the 3D computed tomography described in Chapter 1. The test specimen is tightened by means of a light threaded hole and a screw with thread. After placing the test object, the parameters necessary for successful scanning of the tube are set. In case of incorrectly set parameters, there is an option not to notice defects in the internal structure of the studied object.

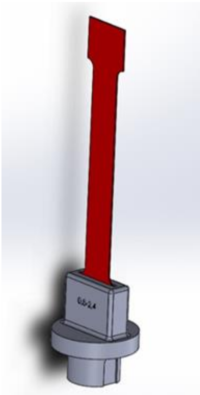

Fig. 4.28. Modeling holder

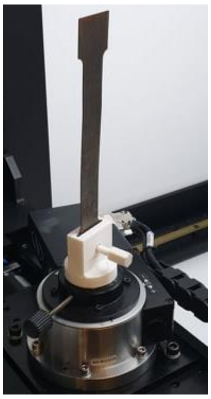

Fig. 4.30. Set object for research

4.11. Study of the hardness of working shafts

4.11.3. Results and discussions

The results obtained are after processing of the metal, approximately after 100 tons of metal have been processed through them. The analysis was performed with a portable hardness tester of the INSIZE brand, model ISH-PHA portable, which has the ability to measure hardness on 4 scales: HB (Brinell), HRC (Rockwell), HV (Vickers), MPa. The life of the support and working shafts is quite long as long as they are operated properly. After the initial work with the support shafts, the time after which they have to be removed for the first grinding is approximately 3000 tons, due to increased roughness or trimming of the shafts. After smoothing the surface, they return to the work cage. The working method of work shafts is the same, with the difference that they are ground after rolling 150 tons of metal. The minimum diameter of the support shafts is about Φ520 mm, and of the working shafts until the diameter Φ185 mm is reached.

The analyzes are reported on the Rockwell scale - HRC. Research shows that the hardness of the shaft has changed by only 1 unit.

4.12. Study of the roughness of working shafts and low-carbon steel

4.12.1. Study of the roughness of working shafts

➢ Used equipment:

• The lathe used to machine the work shafts is the C13MB universal lathe.

• For the needs of the production a universal round grinder from a Bulgarian manufacturer has been chosen. This grinder is based on the principle that the workpiece rotates, the stone remains stationary, and the table on which it is attached is moved.

➢ Experimental results

After grinding the shaft, the roughness is normal - 0.4 µm, and after its rolling work it reaches over-smoothing - 0.042 µm, (Table 4.24). After machining the work roll - grinding, the diameter to be removed is in the order of 0.2 mm.

Table 4.24. Roughness of the working roll

	Roughness, [µm]
Grinding roll	0,4
Worked roll - processed 50 t. metal	0,15
Worked shaft - processed 250 t. metal	0,042

4.12.2. Measurement of roughness of low-carbon steel after rolling of reversible single-cell loom 700

To perform the experiment, an analysis of the roughness of low-carbon metal was made in several states of delivery and processing of metal: hot-rolled coil, purchased cold-rolled coil, and cold-rolled coil from purchased hot-rolled coil, processed on a reversing mill 700 for cold rolling, Table 4.25

Table 4.25 Average roughness of different type of steel

Type of steel	Average roughness, µm
HRS	1,39
Purchased CRS	1,0
Manifactured CRS, 5 % deformation	1,01
Manifactured CRS, 50 % deformation	0,32

4.13. CONCLUSION

This paper presents the method for technological preparation of a test body from the choice of press, the type of punch to the dimensions that must meet the standard EN ISO 6892-1 a test body for tensile strength testing. After testing different thicknesses and hardnesses of the sample body, it becomes clear that there is no pattern in the number of samples that will be prepared, after which the guillotine knives of the punch will have to be sharpened. However, after a study and monitoring of the work process, taking into account the intensity of work, it is necessary to sharpen after about 2 years or when edges begin to appear in the area of cutting the workpiece.

After a thorough analysis of the study using spectral devices, it was found that this method provides information essential for learning and improving the work processes. This is necessary in order to be able to make quick and accurate quantitative analyzes of the chemical composition of the raw material, because from there the whole mode of operation is determined.

After analyzing the high-strength steel grades, it became clear that the replacement of ordinary structural steel grades allows to significantly reduce the metal consumption of manufactured products by using a smaller wall thickness and similar or higher tensile strength. In this way, in addition to maintaining the durability of the product / structure, but significantly reducing its weight, the linear meters of rolled sheet metal are increased, which leads to savings.

During the tensile strength test, a graph is drawn from which the program will calculate parameters important for the analysis of the material. Depending on the material tested, the graphics are different. Low carbon steel has been tested at various stages of processing.

As a result of the developing world, the analysis equipment is being modernized. Therefore, a comparison of the measurement of linear quantities using standard measuring instruments - caliper and micrometer and the modernized 3D computed tomography, which provides more detailed information about what problems may arise in preparing a test body for tensile strength testing. The analyzes show that despite the discrepancy in the measurement by the two methods, the dimensions of the sample meet the ISO standards for width and thickness and do not give a significant error in the subsequent calculation of the mechanical parameters. The analysis with the 3D computed tomography shows detailed defects after cutting off the test body after punching. The thickness on both sides of the sample is crushed from 1.02 mm average thickness in the middle to 0.90 mm. The other defect that is visualized is the appearance of a mustache also due to a worn punch knife.

From the comparative analysis of the geometrical characteristics of a metal test body for tensile strength testing, prepared before and after sharpening of guillotine knives on the press, significant differences were found. From the measurements made on a 3D computed tomograph it was found that when the knives are worn out, large defects occur on the surface of the sample. During the detailed measurement of the width, there is a crushing of the metal on the upper side of the knife, uniformity in the middle and a defect in the lower part of the sample. And the thickness in the final widths is 0.12 mm less, in contrast to the test body prepared after sharpening, where the thickness and width are uniform.

Due to the variety in the hardness and thickness of the workpiece, it is difficult to say after what period of work the guillotine knives of the punch wear out. According to observations of the needs and workload of the current production, it is necessary to sharpen every 2 years. Timely sharpening of guillotine knives on the press can lead to more accurate measurement of tensile strength.

An intermediate inspection of the test specimen for a period of 6 months is recommended, depending on the press load.

A test body holder was created, used in a 3D computed tomograph to analyze the geometric characteristics and structure of the tube. It provides a secure and stable grip to avoid damage and inaccuracies in the examination and analysis of the test specimen, which is essential for quality control. After comparing the dimensions of the new holder for test specimens and the standard for determining the dimensions, it becomes clear that all sizes of flat test specimens with a rectangular shape are comparable to the size of the holder and can be tested. The advantage of the test fixture holder is the reduced time for placing the test specimens in the movable plate, the secure grip and the possibility to place different types of test specimens and does not fall into the scanning area.

The optical method of measurement, TIV technology allows measuring the hardness of different materials without additional calibration. In addition, the static application of the load allows measuring the hardness of thin and small objects, as well as coatings.

Chapter 5

PLAN FOR COMMERCIALIZATION OF SCIENTIFIC RESULTS

Using the latest technological operations and equipment from global manufacturers and brands, the company is focused on developing innovative solutions in the production of pipes and profiles through:

• Quick implementation of new profiles.

• Production of pipes and profiles from high-strength material - up to 520 Mpa.

• Production of complex profiles in combination with material with high tensile strength

5.2. Conclusion:

Through the simulation of a combination of complex profiles and smaller thickness of pipes and profiles and their testing under load shows a significant reduction in the weight of the finished products without compromising their strength and appearance.

CONCLUSION

In the developed dissertation the review, analysis and systematization of methods and means for technological diagnostics of automatic machines and lines are made.

A technological regulation and approach for implementation and operation of the technological equipment for production of thin-walled electro-welded closed profiles from cold-rolled steel is proposed.

Methods for experimental preparation of a test body are proposed, through which tensile strength, spectral analysis and computed tomography are tested.

Experiments were performed with a universal tensile strength testing machine, which analyzes the mechanical properties of the metal.

The chemical composition of the raw material used to correctly determine the operating modes was studied by spectral analysis.

An innovative holder for test specimens has been created, which is protected by the Patent Office of the Republic of Bulgaria, Reg. № 3892 U1 / 23.09.2020. The holder is used in the developed methods for 3D scanning of the internal structure of the test body, aiming at non-destructive analysis of its geometric characteristics. Analyzes show deformation in its shape, defects have formed, due to wear of the press punch. An analysis and recommendation for prevention of the punch, in accordance with its load was made. It was established that the prevention should be carried out within two years.

In-depth analysis of chemical and mechanical indicators contributes to reducing waste in the process. Increases the quality of finished products and performance on time.

SCIENTIFIC AND APPLIED CONTRIBUTIONS:

The contributions to the dissertation are mainly of scientific and applied character and are as follows:

1. After a detailed review, a critical analysis and systematization of methods and tools for technical diagnostic procedures are made.
2. Existing problems and solutions concerning the modern diagnostics of automatic machines and lines are discussed and the influence of ICT on the methods for technical diagnostics is studied.
3. Innovative approaches for diagnostics of automatic machines and lines are proposed.
4. Methods have been developed for: technical diagnostics (testing) through a test body of plastic deformation and tensile strength, graphs of carbon steel at tensile strength, transformation from hot-rolled to cold-rolled sheet, creation of high-strength cold-rolled steel for precision electric welds pipes.
5. Methods have been developed for: design of a new type of innovative test body holder, innovative measurement of geometric characteristics by 3D computed tomography, analysis of the characteristics of the test body before and after punch sharpening .
6. Methods have been developed for: spectral analysis of a metal test body, machining and research of the hardness and roughness of working rolls, testing of the roughness of low-carbon steel after cold rolling.
7. Experimental developments and simulations of different methods in industrial environment are made.
8. The results are analyzed and tested

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