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DEPENDENCE OF ELECTROMAGNETIC PARAMETERS OF PRODUCTS FROM STEEL 09G2S ON THEIR MECHANICAL PROPERTIES

This work presents a method for a non-destructive method for determining the tensile strength, yield strength and relative elongation of steel products by identifying the relationship between mechanical and electromagnetic properties. Coercive force, maximum magnetic permeability and residual magnetic induction were chosen as electromagnetic properties, as the most structurally sensitive parameters to the composition and heat treatment of products. The difference of the work carried out is the use of several physical characteristics simultaneously as control parameters, since multi-parameter control methods provide higher information content and reliability of assessing the state of materials.

The result of the research is a method for determining the relationship between mechanical and electromagnetic parameters. At the same time, the deviation of the values obtained by this method and the actual values during the tensile test does not exceed 5 %.

The proposed method for determining the values of mechanical properties can be used for any steel product and its grade, having previously established, for the corresponding composition of the material, the relationship between mechanical and electromagnetic properties.

Keywords: coercive force, tensile strength, non-destructive testing, mathematical model, mechanical properties of steel.

Introduction

Currently, uniaxial tension on a tensile testing machine is used to determine the mechanical properties of steel products. The result of the test is a tensile diagram, according to the graph of which the tensile strength, yield strength and relative elongation are determined. In accordance with many standards used in manufacturing plants, the determination of these mechanical characteristics is mandatory. For example, for seamless pipes according to GOST 632-80 «Casing pipes and couplings for them», the normalized indicators are tensile strength, yield strength and relative elongation. Mechanical tensile testing is accurate, but inspection requires cutting a «template» and then making a standard test piece. In this regard, further exploitation of the product is impossible, or if this product is long, then metal is consumed. In addition, due to the fact that the tensile test is destructive, the control of products is carried out by sampling (one of any quantity –a batch), which does not ensure the control of each unit of the product.

The use of a non-destructive method for determining mechanical properties is promising. One of these methods is electromagnetic. Electromagnetic control methods have been widely used in industry for a long time. However, their applicability is confirmed only in the control of discontinuities in the metal, and only hardness is quantified – through the measurement of the coercive force, which has a high error.

Further development of the electromagnetic method control is predicted in two directions. The first is the search for new control parameters, the development of new methods and measuring transducers that make it possible to measure the physical characteristics that are control parameters. The second direction, which significantly expands the range of non-destructive testing physical methods application, is the use of several physical characteristics simultaneously as control parameters.

Materials and methods of research

The beginning of the experiment was to conduct heat treatment of steel samples of grade 09G2S. The heat treatment regime is high-temperature heating at 900 °C and hardening followed by tempering in the temperature range from 350 to 700 °C. Samples sized 10×10×100 mm were heated in an electric furnace SNOL 6.7/1300. Subsequent cooling was carried out by lowering the samples into water with a water temperature of 20 °C.

After the heat treatment of the samples, namely, quenching followed by tempering, using a coercimeter and a teslameter, the maximum values of magnetization and tension, as well as the coercive force and residual magnetic induction, were measured, the values of which are indicated in the diagrams of Figure 1.

Having determined the maximum values of the tension and magnetization of the samples, the maximum magnetic permeability of each sample was calculated using formula (1), the values of which are summarized in Table 1.

$$\mu_{max}=B_{max}/H_{max}, \quad (1)$$

where B_{max} – maximum magnetic field strength of the sample, T;

H_{max} – maximum value of sample magnetization, A/m.

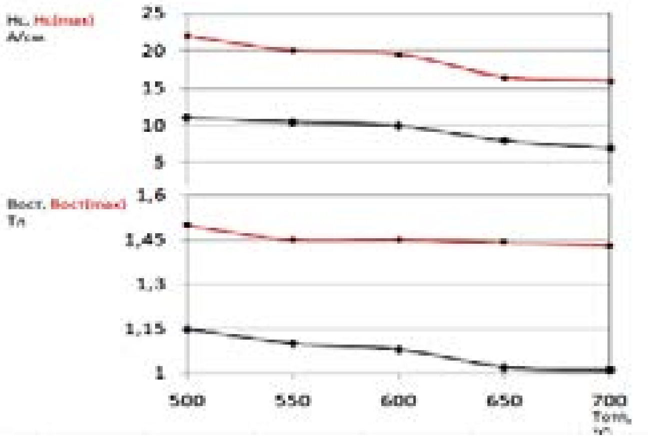

Figure 1 – Magnetic properties of a sample of steel 09G2S

The values of the coercive force corresponded to the values of the magnetization at zero magnetic field strength, and the values of the magnetic induction, on the contrary, corresponded to the magnitude of the strength at zero magnetization.

Table 1 – Values of the steel samples maximum magnetic permeability

Maximum magnetic permeability	Temperature of tempering, °C							
	350	400	450	500	550	600	650	700
	221,3	111,3	166,1	73,7	72,2	73,5	81,6	108,0

After the magnetic characteristics were measured, the actual mechanical characteristics were measured on a tensile testing machine according to GOST 1497-84, the results of which are summarized in Table 2. In this case, the tempering temperature in the range from 350 to 700 °C was the variable parameter of the heat treatment.

Table 2 – Values of the tested samples mechanical properties

Temperature of tempering, °C	Tensile strength, MPa	Yield strength, MPa	Relative elongation, %
350	880	685	10
400	845	643	10
450	801	612	11
500	782	587	12
550	763	564	12
600	745	547	13
650	728	530	14
700	711	519	15

Results and discussion

Having determined the values of the samples magnetic properties, we compiled an experiment planning matrix for steel 09G2S, and summarized the data in Table 3.

Table 3 – Matrix on a standardized scale for steel 09G2S

Experience number	(x_1)	(x_2)	(x_3)	$(У_1)$	$(У_2)$	$(У_3)$
1	-1	-1	-1	880	685	10
2	1	-1	-1	845	643	10
3	-1	1	-1	801	612	11
4	1	1	-1	782	587	12
5	-1	-1	1	763	564	12
6	1	-1	1	745	547	13
7	-1	1	1	728	530	14
8	1	1	1	711	519	15

Using regression analysis in Excel, we derive a mathematical model for controlling mechanical properties by a non-destructive method for steel 09G2S.

To determine the tensile strength, the equation takes the form:

$$У_1=781,875-11,125x_1-26,375x_2+45,125x_3$$

To determine the yield strength:

$$У_2=585,875-11,875x_1-23,875x_2+45,875x_3$$

To determine elongation:

$$У_3=12,125+0,375x_1+0,875x_2-1,375x_3.$$

In order to confirm the reliability of the proposed method for determining the mechanical properties, pipes made of steel 09G2S were taken for testing. Table 4 shows the results of applying the proposed method. Having determined the equations of dependencies, these pipes were thermally processed according to a randomly selected mode, for example, a tempering temperature of 620 ºC was taken.

Further, the electromagnetic parameters were measured on each released product. By substituting the average of the three values for each of the parameters into the dependency equations available for this steel, we determined the calculated values. After that, from each product, standard samples were made for tensile testing in accordance with GOST 1497-84 and the actual values of mechanical properties were obtained.

Table 4 – Measurement results and regression equations

Temperature of tempering, ºC	Value	H_c, A/cm	µ_max	B, T
500	= 819 МПа	12,4	580	1,05
	=745 МПа			
	=11,5			
550	= 771 МПа	11,7	596	1,01
	=698 МПа			
	=12,8			
600	= 739 МПа	10,8	612	0,96
	=545 МПа			
	=13,8			
650	= 688 МПа	10,3	641	0,77
	=525 МПа			
	=14,8			
700	= 650 МПа	10,1	652	0,53
	=480 МПа			
	=15,8			

Table 5 shows the data calculated according to the equations of dependences, and the actual values of mechanical properties, determined by tension of standard samples, which confirm the reliability and accuracy of the proposed method for determining mechanical properties.

Table 5 – Convergence of results

Mechanical properties of products at a tempering temperature of 620 ºC			
Calculated (according to regression equations)		Actual (from tensile tests)	
$\sigma_в$,, MPa	715	$\sigma_в$,, MPa	731
$\sigma_{0,2}$, MPa	668	$\sigma_{0,2}$, MPa	693
δ, %	16,2	δ, %	16,5

The measurement error is 1.8–3.6 %, that is, less than 4 %, which is quite accurate.

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Conclusions

Of the many testing methods used to determine the mechanical properties of steel products, as well as excluding the influence of the size and shape of the tested products, non-destructive electromagnetic testing is promising. The most sensitive parameters are coercive force, residual magnetic induction and maximum magnetic permeability. The use of three magnetic parameters in combination in the control of steel products contributes to an increase in the reliability and accuracy of measurements, which is confirmed by an accuracy of 96.4%.

The use of a new method for determining the mechanical properties of steel products will reduce the time of testing, due to the absence of the need to select "templates" and prepare samples for testing, eliminate the use of bulky test equipment used for destructive testing methods with small-sized devices, and also make it possible to further use the controlled product.

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09Г2С БОЛАТЫНАН ӨНІМДЕРДІҢ ЭЛЕКТРОМАГНИТТІК ПАРАМЕТРЛЕРІНІҢ ОЛАРДЫҢ МЕХАНИКАЛЫҚ ҚАСИЕТТЕРІНЕ ТӘУЕЛДІЛІГІ

Бұл жұмыста механикалық және электромагниттік қасиеттер арасындағы тәуелділікті анықтау арқылы болат өнімдерінің беріктігін, кірістілігін және салыстырмалы ұзаруын анықтаудың бұзылмайтын әдісі келтірілген. Электромагниттік қасиеттер ретінде коэрцитивті күш, максималды магнит өткізгіштігі және қалдық магниттік индукция, өнімнің құрамы мен термиялық өңделуіне ең құрылымдық сезімтал параметрлер ретінде таңдалды. Жүргізілген жұмыстың айырмашылығы бір уақытта бірнеше физикалық сипаттамаларды бақылау параметрлері ретінде пайдалану болып табылады, өйткені бақылаудың көп параметрлі әдістері материалдардың жай-күйін бағалаудың жоғары ақпараттылығы мен сенімділігін қамтамасыз етеді.

Зерттеу нәтижесі механикалық және электромагниттік параметрлер арасындағы тәуелділікті анықтау әдісі болып табылады. Бұл ретте, осы әдіс бойынша алынған мәндердің және созылуға сынау кезінде нақты мәндердің ауытқуы 5 % - дан аспайды.

Механикалық қасиеттердің мәндерін анықтаудың ұсынылған әдісін кез-келген болат бұйымға және оның маркасына қолдануға болады, бұған дейін материалдың тиісті құрамы үшін механикалық және электромагниттік қасиеттер арасындағы байланыс орнатылады.

Кілтті сөздер: коэрцитивті күші, беріктік шегі, бұзылмайтын бақылау, математикалық модель, болаттың механикалық қасиеттері.

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ЗАВИСИМОСТЬ ЭЛЕКТРОМАГНИТНЫХ ПАРАМЕТРОВ ИЗДЕЛИЙ ИЗ СТАЛИ 09Г2С ОТ ИХ МЕХАНИЧЕСКИХ СВОЙСТВ

В данной работе приведена методика неразрушающего способа определения временного сопротивления, предела текучести и относительного удлинения стальных изделий посредством выявления зависимости между механическими и электромагнитными свойствами. В качестве электромагнитных свойств были выбраны коэрцитивная сила, максимальная магнитная проницаемость и остаточная магнитная индукция, как наиболее структурно-чувствительные параметры к составу и термической обработке изделий. *Отличием проведенной работы является использование одновременно нескольких физических характеристик в качестве параметров контроля, так как многопараметровые методы контроля обеспечивают более высокую информативность и достоверность оценки состояния материалов.*

Результатом исследования является методика определения зависимости между механическими и электромагнитными параметрами. При этом, отклонение значений, полученных по данному способу, и фактическими значениями при испытании на растяжение, не превышает 5 %.

Предлагаемый способ определения значений механических свойств может быть использован для любого стального изделия и ее марки, установив предварительно при этом, для соответствующего состава материала, зависимость между механическими и электромагнитными свойствами.

Ключевые слова: коэрцитивная сила, предел прочности, неразрушающий контроль, математическая модель, механические свойства стали.

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