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DEVELOPMENT OF PRODUCTION TECHNOLOGY FOR POLYMER COATED WIRE BASED ON THE STUDY OF THE STRESS STATE SCHEME IN THE PROCESS OF DRAWING

Abstract. *The relevance of the work is to develop a technology for the production of polymer-coated wire. This caused the need to study the stress-strain state in the process of drawing, as well as the need to consider modern polymer coatings and the modes of their application to the base material. The purpose of this study is to determine the mechanical characteristics of real polymer films, as well as to determine the rheological model of the polymer deformation process for the use of the developed mathematical model in determining the stress-strain state in the drawing process of metal-polymer systems. Polytetrafluoroethylene was chosen as the polymer coating material. The main research method was mathematical modeling of the steel-polymer composition drawing process, which was carried out in the SIMULIA Abaqus software package. The novelty of the study lies in the fact that the conducted studies of the wire stress state and the assessment of the cohesive stability of the coating allowed us to improve the basic drawing technologies. The results of changes in the thickness of the coating in the process of drawing, the mechanism of deformation of polytetrafuoroethylene allow us to conclude that it is impractical to use this technology for wire of large diameters. Also, based on the results of the study, to obtain a wire with an increased level of anticorrosive properties it is recommended to apply a polymer coating before the last transition of the route and then drag it to the final size.*

Key words: *the process of drawing, wire, coating, polymer-coating materials, polytetrafluoroethylene coating, stress strain state scheme.*

A study of the stress-strain state in the process of drawing was conducted and a technology for producing polymer-coated wire was developed.

Mathematical modeling of the drawing process of a steel-polymer composition was carried out in the SIMULIA Abaqus software package. There was created a model of the behavior of a two-component wire in the deformation zone in the process of drawing. The effect of the main technological parameters on the stability of the shell was studied. As a result, it became necessary to determine the rheological model of deformation of the polymer used as a coating. The mechanical properties of the coatings are included as set parameters in the equations of the system for determining the stress-strain state of elements when drawing the composition [4]. Therefore, the purpose of this study is to determine the mechanical characteristics of real polymer films, as well as to determine the rheological model of the polymer deformation process. The developed mathematical model can be used to determine the stress-strain state of the composition in the drawing processes of metal-polymer systems. Polytetrafluoroethylene was chosen as the polymer coating material.

The analysis of the obtained indicator stretch diagrams of polytetrafluoroethylene films showed that the value of the absolute elongation of the samples corresponding to the point of transition of the material from the elastic state to the plastic state is no more than 0.5% of the total absolute elongation corresponding to the beginning of neck formation on the sample [5]. Therefore, the elastic component of deformation can be ignored in drawing processes if the degrees of compression and drawing coefficients on single passes are high enough. A rheological model of a polytetrafluoroethylene-based material is transformed into a hard plastic Mises environment. The strain resistance for such an environment does not depend on either the speed or the strain rate and is 95-100 MPa.

Modeling the process of drawing steel wire with polytetrafluoroethylene coating was to satisfy the following conditions.

Rheological properties of the materials under study:

– steel 20: tensile diagram, Young's modulus 210 GPA, Poisson's ratio 0.3, yield strength 325.36 MPa, tensile strength 473.69 MPa, elongation 14.14 %, density 7800 kg / m^2;

– coating: Young's modulus 100 GPA, Poisson's ratio 0.35, yield strength 100 MPa, tensile strength 100 MPa, density 3000 kg/m2;

– drawing route: 3,2 – 2,65 – 2,2 – 1,85 – 1,5 – 1,2 mm;

– the coating thickness is 100 microns;

– an extended model of Ammon-Coulomb friction that takes into account shear stresses;

– the coefficient of friction is 0.08;

– drawing speed: 2-10 m/s.

Boundary conditions:

– the front end is absolutely rigid and has one degree of freedom (moving only in the longitudinal direction);

– the draw plate is modeled as an absolutely rigid body with zero degrees of freedom;

– the size of the final coating element is 0.03 mm;

– the final size of the wire is 0.23 mm;

– ductile damage.

The distribution of stress-strain state parameters in the process of drawing coated wire from a diameter of 3.2 mm (initial coating thickness-100 microns) to a diameter of 1.2 mm, at a drawing speed of 2-10 m/s, is shown in figure 1.

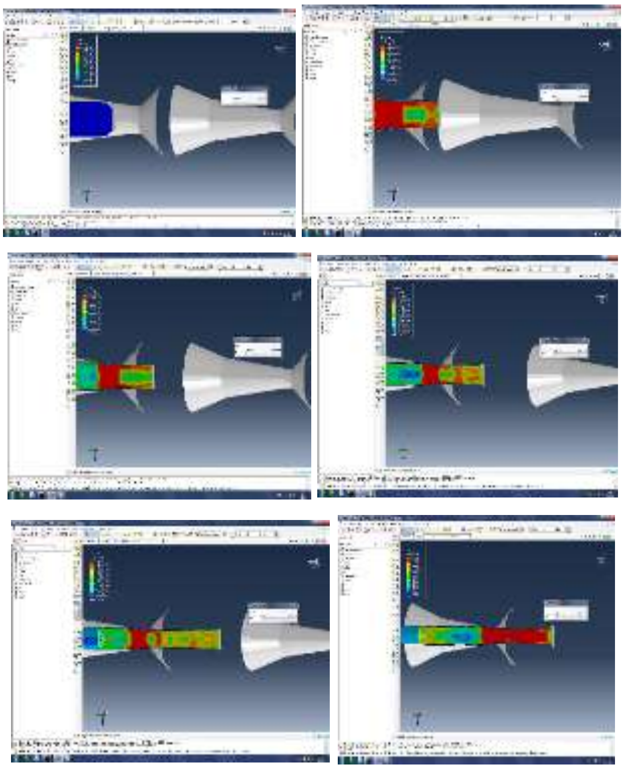

Fig. 1. The results of finite element modeling of the stress-strain state when drawing wire coated with polytetrafluoroethylene

To solve the problems of determining the stable drawing of compositions with a significant difference in the mechanical properties of materials, the criteria for the stable behavior of coatings in the deformation zone are determined [6]. When setting the problem of determining the stress state of composition elements, the assumption was made that the corresponding components of the strain rate tensor for the soft and hard components of a layered system at the interlayer boundary are equal. The compliance of this assumption with the actual conditions of the drawing process determines the feasibility of applying the kinematic stability criterion, namely

$$K_{CS} = \frac{\xi_{ij}^{S}}{\xi_{ij}^{H}} = \frac{\xi_{I}^{S}}{\xi_{I}^{H}} = 1.$$

To solve the problem of identifying areas for sustainable drawing compositions with a significant difference in mechanical properties of the layered system it is required to select a criterion to evaluate the influence of technological parameters on the type of surface loading with respect to the form of the yield surface in the soft component [1]. Using this criterion, it is possible to compare the stress intensity in the coating with the current yield strength or tensile strength of the surface layer.

It is reasonable to present this criterion as a criterion for the cohesive stability of the surface layer-K_{CS}

$$K_{CS}=\frac{\sigma_i^S}{\sigma_{TS}^S}\leq .$$

At $K_{CS}>1$, the stress intensity values exceed the tensile strength of the surface layer, and it is possible to break the cohesive bonds in the surface layer.

For the stable process of joint plastic deformation of the layered system according to the scheme " hard base-soft coating”, the condition must be met on the inter-layer border:

$$\sigma_i^H = \sigma_i^S.$$

Then the criterion for cohesive stability is the following condition:

$$K_{CS} = \frac{\sigma_i^H}{\sigma_{TS}^S} \leq 1.$$

The condition for the plastic flow of a solid component is the coincidence of the loading and flow surfaces. Then, taking into account the plasticity condition, the criterion of cohesive stability will take the form

$$\sigma_{TS}^S > \frac{\xi_i}{\xi_{zz}}\sqrt{\frac{4}{3}\sigma_S^2 - 4\sigma_{zr}^2}.$$

To determine the stability of the process of joint plastic deformation of elements of a layered system according to the proposed criteria, two approaches are possible:

– determination and evaluation of kinematic parameters from the pre-calculated stress state using the criterion. In this case, the condition for fulfilling the cohesive stability criterion of the coating is set;

– calculation of the stress state and evaluation of the process by the criterion of cohesive stability based on kinematic parameters under the specified condition of satisfying the kinematic criterion.

The stability of polytetrafluoroethylene coatings in the process of drawing metal-polymer compositions was evaluated using the criterion of cohesive stability, provided that the kinematic stability criterion was met. The values of the half-angle of the draw plate from 0.50 to 100; the coefficient of a single exhaust from 1.05 to the values of single hoods of the basic technology with an increase in the number of transitions [10]. The calculation was performed for various kinds of thickness of the polymer layer in the range from 5 to 50 microns. The interlayer boundary was set as a straight line without taking into account the microgeometry parameters of the wire surface. The calculation was performed for the case of entering the composition into the deformation zone.

However, as the calculation results show, none of the studied technological schemes can reduce the criterion of cohesive stability to the value that determines the area of stable drawing of metal-polymer compositions.

Thus, for a smooth inter-layer border, the process of joint plastic deformation of polytetrafluoroethylene with steel is impossible, and the destruction of the coating will always occur. This mechanism of coating behavior leads to the formation of zones of non-contact deformation [2].

The formation of zones of non-contact deformation and destruction of the polymer component of the composite system in the process of drawing is well confirmed by experimental data. As a result of drawing wire with coatings based on polytetrafluoroethylene, the thickness of which exceeds the height indicators of the microgeometry of the interlayer border, under any drawing conditions, the process of clogging the input cone of the tool with a polymer material occurs [5]. However, the same experiments show evidence of the presence of a coating of polytetrafluoroethylene at the exit of the wire from the draw plate channel. The presence of a coating is observed and confirmed by an increase in the corrosion resistance of such a wire compared to the wire without a coating. In addition, the experiments show a reduction of effort by 15-20 % when drawing a wire with a polytetrafluoroethylene coating, which indicates the presence of a separating polymer layer in the deformation zone.

Based on theoretical and experimental data, a four-stage mechanism of polymer material deformation is proposed [3].

At the first stage, zones of non-contact deformation are formed and the surface layer is destroyed at the peaks of micronerities at the entrance to the deformation zone.

At the second stage, the polymer material enters the deformation zone at the indentations of micro-surfaces with selective deformation, due to which non-contact zones are formed at the entrance to the deformation center.

At the third stage, the "polymer pocket" is completely located in the deformation zone and the elements of the composition are deformed together.

At the last stage, when the polymer pocket exits the deformation zone, non-contact zones are formed, which contribute to an equal distribution of the coating thickness at the final diameter of the composition [4].

Based on the developed mathematical model, the influence of technological parameters (degree of deformation, yield strength of the coating, half-angle of the drawing plate, back-tension) on the stress state of the coated wire in the process of drawing was studied.

The technology of production of mesh wire with a protective polymer coating was developed.

Analysis of the processes of obtaining wire coatings, as well as the analytical and experimental studies allowed us to propose two main technological stages of the formation of polymer wire coatings:

– application of the coating to the final diameter;

– application of the coating to the sample with subsequent drawing.

The development of a complex technological process for obtaining polymer-coated wire passes through two stages. At the first stage, it is necessary to develop a process for forming high-quality defect-free coatings for wire of a final diameter from an aqueous suspension of polytetrafluoroethylene. At the second stage, it is necessary to develop a technology for drawing wire with a polymer coating, based on analytical data.

The process of applying a polymer coating consists of the following main technological stages that ensure the achievement of the required level of functional properties of the coating:

– preparation of the wire surface;

– forming the coating layer;

– heat treatment.

At the stage of preparing the surface of the wire for applying the coating with an aqueous suspension, a chemical method and jet treatment are offered. The influence of the parameters of the jet processing (the type of abrasive material and its granulometric composition, compressed air pressure, the angle of incidence of the abrasive) on the parameters of the wire surface roughness is studied.

At the stage of applying the coating, the influence of the viscosity of the water suspension and the height parameters roughness of the wire surface on the thickness of the formed polymer layer was studied [3].

At the stage of heat treatment, the influence of temperature and drying time on the degree and speed of the dewatering of the coating was studied. Based on the proposed method of determining the adhesive strength of the polymer coating, the influence of the polymerization temperature on the level of adhesive properties of the coating and the base was studied [7].

The modes of forming a polytetrafluoroethylene coating from an aqueous suspension to a wire are shown in table 1.

The technology of applying the coating to the final diameter allows you to effectively obtain high-quality polytetrafluoroethylene coatings on wire with a diameter of more than 1.8-2 mm. The research shows that the process of coating on smaller diameters is difficult due to the formation of coating defects (discontinuities, leaks, etc.), the complexity of managing the surface preparation process (both chemical and jet methods).

In addition, production and experimental studies allow us to conclude that the corrosion resistance of coated wire is increased compared to the technology of coating the final diameter. In the process of drawing, the coating is compacted, microcracks and pores are healed, and the polymer material is evenly redistributed along the cross section and length of the wire [6]. As a result, of these processes, the corrosion resistance of drawn wire increases by an average of 10%. Therefore, in some cases, to increase the level of protective properties, it is advisable to conduct additional wire drawing of the specified diameters.

Table 1

The modes of application of polytetrafluoroethylene coatings

Technological operation	Operating mode
Surface preparation 1. Chemical method: - rough degreasing; - electrochemical degreasing; - etching; - phosphating; - washing. 2. Jet method	composition of g / l: labomide-203. Temperature 70-80^{0}C. Time 15-20 s; composition of g / l: Na_3PO_4-20-40; NaOH – 30-50. T – 70-80 ^{0}C, time – 10-15 s, V-10-12 V, I-8-12 A / dm^2; composition of g / l: H_2SO_4 – 120-150. T – 70-80^{0}C, time – 8-10 s; g/l composition: phosphate-9-40-45. T – 80-90^{0}C, time – 25-30 s; running or distilled water; the particle size of the abrasive is 0.6 mm, the distance of processing 0.15 m air pressure 0.35 MPa.
Application of the coating	An aqueous suspension of polytetrafluoroethylene, a concentration of 70-75 %, viscosity 40 cst .
Heat treatment: - drying; - polymerization	T – 90^{0}C; time – 25-30 s; T – 410-415 ^{0}C; time – 2.5-3 min.

Drawing wire with a polytetrafluoroethylene coating is used in the production of polymer-coated wire with a diameter of less than 1.8-2 mm. In this case, the sample is drawn with a pre-applied polytetrafluoroethylene coating along the entire drawing route. The conducted studies of the wire stress state and the assessment of the cohesive stability of the coating allowed us to correct the basic drawing technologies [9]. The adjustment was made by changing the drawing route by increasing the coefficient of unit drawing from 1.38-1.40 (base route) to 1.46-1.50 for the route of drawing polymer-coated wire. The increase in individual compressions was carried out in order to increase the numerical values of the criterion of cohesive stability of the polymer coating inside and at the exit of the deformation focus, taking into account the coefficient of safety margin during drawing. When producing polymer-coated wire with a diameter of more than 2 mm with an additional drawing operation, there are two possible variants of the technology. The first option corresponds to the technology of obtaining wire with a coating of small diameters, i.e., applying to the sample and drawing the wire along an adjusted route [8]. However, studies of changes in the thickness of the coating in the process of drawing, the mechanism of deformation of the polytetrafluoroethylene material allow us to conclude that it is impractical to use such a technology for wire of large diameters. The use of this technology option reduces the coefficient of using the polymer material due to the partial destruction of the coating at the entrance to the deformation zone at each transition.

To obtain a wire with an increased level of anti-corrosion properties, it is recommended to apply a polymer coating before the last transition of the route and then to draw it to the final size. The coefficient of unit drawing according to the results of calculations should vary from 1.48 to 1.52. To implement this technology, the basic routes of wire drawing were adjusted. It should be noted that this option increases the cost of polymer-coated wire due to the break in the cycle of the drawing process for applying the coating before the last transition. Therefore, it is advisable to apply the coating to the wire exposed to aggressive media (acids, alkalis, sea water, etc.) before the last transition. For a standard mesh, it is sufficient to use a wire with a coating applied to the final size.

An increase in the numerical values of the criterion of cohesive stability in the process of drawing leads to the destruction of the polymer coating at the entrance to the draw plate (due to the formation of zones of non-contact deformation), clogging of the input channel and, as a result, to an increased probability of wire breakage. It is possible to use a special tool to suppress such zones by increasing the share of hydrostatic pressure.

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INFORMATION ABOUT THE PAPER IN ENGLISH

РАЗРАБОТКА ТЕХНОЛОГИИ ПРОИЗВОДСТВА ПРОВОЛОКИ С ПОЛИМЕРНЫМ ПОКРЫТИЕМ НА ОСНОВЕ ИЗУЧЕНИЯ СХЕМЫ НАПРЯЖЕННОГО СОСТОЯНИЯ В ПРОЦЕССЕ ВОЛОЧЕНИЯ

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Аннотация. *Актуальность работы заключается в необходимости разработки технологии производства проволоки с полимерным покрытием, что вызвало необходимость исследования напряженно-деформированного состояниz при волочении, а также необходимость рассмотрения современных полимерных покрытий и режимы их нанесения на материал-основу. Целью данного исследования является определение механических характеристик реальных полимерных пленок, а также определение реологической модели процесса деформирования полимера для использования разработанной математической модели при определении напряженно-деформированного состояния композиции в процессах волочения металл-полимерных систем. В качестве полимерного материала покрытия был выбран политетрафторэтилен. В качестве основного метода исследования было выбрано математическое моделирование процесса волочения сталь-полимерная композиция, которое осуществлялось в программном комплексе SIMULIA Abaqus. Новизна исследования заключается в том, что проведенные исследования напряженного состояния проволоки, оценка по критерию когезионной устойчивости покрытия позволили скорректировать базовые технологии волочения. Результаты проведенных исследований изменения толщины покрытия при волочении, механизма деформирования фторопластового материала позволяют сделать вывод о нецелесообразности использования такой технологии для проволоки больших диаметров. А также по результатам исследования можно сделать вывод о том, что для получения проволоки с повышенным уровнем антикоррозионных свойств рекомендуется нанесение полимерного покрытия перед последним переходом маршрута и последующее волочение на конечный размер.*

Ключевые слова: *волочение, проволока, покрытие, полимерные материалы покрытия, политетрафторэтилен, схема напряженно-деформированного состояния.*

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