THEORETICAL JUSTIFICATION FOR CALCULATING THE PLASTIC DEFORMATION OF THE CLAD LAYER

Abstract. One of the main ways widely used to eliminate residual deformations and improve the structure when cladding the surfaces of parts is running-in. The metal is rolled in depth in the weld zone to create plastic elongation deformations in the longitudinal and transverse directions.

Rolling-in is carried out by steel cylindrical rollers. Some of the basic parameters that characterize the technological process are: pressure during running-in on the roller, radius and width of the working part of the roller, metal thickness in the area of running-in, material state parameters. Complete elimination of residual strains is achieved in the case when plastic elongation strains created by rolling in the layer and adjacent areas of the base metal will be equal in value to the residual plastic strain of shortening in these areas. The residual longitudinal stresses in this case may be close to zero. Along with the elimination of longitudinal residual deformations, running-in leads to the elimination of structural displacements caused by the loss of stability from the action of longitudinal residual stresses. The recommended influence parameters are found by approximate formulas according to the scheme of uniaxial stress state. To adequately take into account the effect of settling along the thickness of the heated material, calculating the change in residual stresses and deformations, it is necessary to study the stress-deformed state of the material of the layer on the basis of which the deforming force and total power are also calculated. The thermal process arising in the deformation zone is investigated. Thermal processes occurring during the surfacing of parts and surface plastic deformation largely determine the physical and mechanical properties and wear resistance of the surface layer and have a great influence on the processes and performance of plastic deformation. Temperatures are also set along the length of the deposited part in the deformation zone at the moment of disconnection of the welding arc, based on the assumption that the temperature of the limit state of the deposited part in the deformation zone is equal to the temperature of the extreme deposited roller.

As described above, at increased temperatures, the calculation of metal processing processes must be carried out using equations of the state of the simplest creep theories. The most general in this respect is the theory of hardening. In the case under consideration, in contrast to the conventional process of rolling between rotating drive rolls, the deforming roller performs plane-parallel motion, and different friction conditions take place on the contact surfaces.

Keywords. Rolling, cladding, temperature, technological process, deformation.

Introduction.

The most important task of machine-building production is to increase the reliability and durability of products. The solution to these issues directly depends on the creation and development of progressive resource-saving technological methods for improving the quality of
parts and increasing their wear resistance, reducing costs, increasing productivity, increasing durability and improving working conditions.

Weld layer run-in belongs to the class of metal forming processes. The calculation problems of metal forming processes are usually solved based on one of the body models accepted in plasticity theory (most often rigid ideal plastic, sometimes elastic ideal plastic or rigid strengthening body). Since in this case the equations of state do not include deformation rates, these solutions do not allow reflecting the speeds of movement of the deforming tool on the forming forces and the stress-strain state of the deposited layer.

This effect is particularly significant if the metal deforms at high temperatures and stresses. In this case, despite the relatively short deformation time, the viscosity of the metal is essential, and therefore the calculations of metal processing processes should be based on the equations of state in which the deformation rates are contained, that is, on the equations reflecting the rheonomic properties of the metals - on the equations of creep theory.

**Materials and methods.**

Rheological models for describing technological problems of plastic formation of metals are used in the works of G. Genki, A. Ilyushin, A. Ishlinsky, N. Malinin, K. Romanov, O. Zenkovich, N. Cristescu, S. Tang, D. Durban, etc. [1,2]

The first attempts to apply the equations of rheonon bodies for the solution of technological problems belong to A.A.Ilyushin, A.Yu.Ishlinsky, G.Genki. Further development - this direction received in works of N.N.Malinin and others. [1-3], in which technological problems are solved on the basis of technical theories of creep, such as the theory of flow and hardening, as well as with the help of the equation of state of a nonlinear-viscous body. The principle possibility of investigating the processes of shaping change of rheonite bodies is shown in the works of A.A. Ilyushin [4], A.Yu. Ishlinski [5] and G.Genka [6], in which the viscoplastic body deformation equation is used

$$\sigma_e = \sigma_T + \gamma \xi_e,$$

where $\sigma_e$ and $\xi_e$ is equivalent stress and equivalent strain rate respectively;

$\gamma$ is a constant, proportional to the viscosity of the material;

$\sigma_T$ is the yield strength ($\sigma_T$ and $\gamma$ are determined experimentally;

$\sigma_e < \sigma_T$ the medium does not undergo deformation).

In the works of N.N. Malinin and his employees [1], calculations of technological processes of metal processing are based on equations of the theory of creep (flow or strengthening).

The work of Genki [6] considers the rotation of a rolling roll in a plastic material. In the paper by A.A. Ilyushin [4], basic equations of viscoplastic flow are derived and a number of problems are considered, including the rotation of a cylinder in a viscoplastic medium. The paper [5] by A. Yu. Ishlinskii solved the problem of rolling and drawing strip under flat deformation conditions.

Some technological processes (e.g., welding) are associated with local heating of material to high temperature. In such processes, uneven thermal expansion creates stresses whose intensity may exceed the plasticity limit of the material at the current temperature. This leads to non-zero deformation and stresses being retained in the material after cooling, which may adversely affect its properties [7].

In [8] the thermal process occurring in the deformation zone is considered. Thermal processes occurring during cladding of parts and surface plastic deformation largely determine
the physical and mechanical properties and wear resistance of the surface layer, and have a great influence on the processes and performance of plastic deformation [9,10].

Based on the works of V.I. Makhnenko, A.A. Orlov, N.I. Boyko, based on the known methodological approaches of N.N. Rykalin, a number of solutions were obtained in work [8] to determine the temperature of the deposited metal in the zones of plastic deformation.

The temperature of the clad roll in the deformation zone was determined by the well-known equation of A.A. Orlov, as applied to cladding thick-walled or solid cylinders.

Surface plastic deformation provides a change in the structure of the metal, but without its complete recrystallization. The most important characteristic of the surface layer state is residual stresses.

When designing surface plastic deformation operations that replace, for example, turning, grinding, polishing or finishing operations, remember the following advantages of surface plastic deformation:
- there are no thermal defects;
- stable machining processes ensuring consistent surface quality
- Surface roughness can be reduced by several times in a single process step or operation;
- favourable form of micro-irregularities with a high proportion of the support area is created
- favourable compressive residual stresses in the surface layer are created;
- micro-hardness in the surface layer increases smoothly and steadily.

**Results.**

The residual stresses in the plates are usually determined in two directions: along the seam $\sigma_x$ and across the seam $\sigma_y$, the third component $\sigma_z$ in a component up to 15-20 mm thick is negligible.

The main problems in determining longitudinal stresses are based on known assumptions and hypotheses, which do not always give results that can be confirmed by experiments [11, 12].

Computational methods are widely used to determine the residual strains. The problem of determining deformations (displacements) from welding presents two sections, thermomechanical and strain. The thermomechanical solution is reduced to determining the magnitude of shrinkage force, transverse shrinkage along the length and thickness of the joint and other deformation elements occurring in the welded joint area. Initial strain elements determined from the thermomechanical solution are related to welding conditions, type of connection and other factors affecting the development of deformations in the welding process.

In [13] calculation of strain resistance in thermomechanical treatment (TMP) of welded surfaces is given. A one-dimensional problem for stress determination at the deformation point, based on the planar cross-section hypothesis, is considered. It is believed that normal stresses in cross section are constant, the deformed state is flat.

The condition of plasticity in the deformation focus is recorded using the so-called forced yield strength in the form:

$$K = \beta \sigma_y.$$

Here $\sigma_y$ is the basic yield strength, $\beta = 1-1.5$ the Lode coefficient.

It is believed that the forced yield strength does not change in contact. As a result, an expression for calculating the deformation force at the contact surface of the roller and the deformed layer is obtained, i.e. the resistance to deformation during TMO of the cladding surfaces.
The disadvantage of this work is that equation (2) does not describe the dependence of the stressed-deformed state of the material in the deformation zone and the deformation force at elevated temperatures on the speed of roller movement. Experimental studies by many authors [14,15] show that equation (2) does not describe the state of metals at elevated temperatures and the calculation of technological processes must be based on a rheological model. Relatively general is the equation of state based on creep theory, Ludwick-Nadia-Davenport hardening theory [15]. From the point of view of the geometry of deformation the drawback of this work is the hypothesis of planar cross-sections and for a more accurate description of the stressed-deformed state of the material it is necessary to consider the problem in a multidimensional formulation (two or three dimensional).

Temperature determination along the length of the welded pattern in the deformation zone at the moment of welding arc turning off is based on the assumption that temperature of the limit state of the welded pattern in the deformation zone equals temperature of the last weld bead:

$$T_{nn} = \sum_{i=1}^{i-1} T^{i-1}_{im} + T^{i-1}_{Al} \cos \phi_{a} + T_0,$$

(4)

where $m$ is the total number of rolls deposited.

The temperature of any point of the deposited metal in the deformation zone of the part immediately after the termination of the source, using the H.H. Rykalin equation, is presented in the form

$$T_{Alh} = T_{nn} \cdot \psi_{Al} \left( p_{Ai} ; \tau_{Ai} \right) _{C} C^0,$$

(5)

where $\psi_{Al}$ is the coolant coefficient of the determined point in the deformation zone.

Experimental data show [3] that deformation of metals during machining at high temperatures is characterized by a significant influence of strain rates on stresses. Therefore, calculation of stresses and strains must be carried out on the basis of the equation of state of a rheon body.

In the simplest case of uniaxial tension, a theory called creep theory is required to determine the relationship between deformation, stresses, stress rates and time.

It must make it possible, on the basis of simple tests of the material, e.g. on the basis of experimental investigation of creep under constant tension, to describe the deformation of the material in the general case of time-varying stresses and strains and to determine the law of variation of deformations in accordance with a stated law of change of tension and vice versa. In the particular case it should make it possible to construct relaxation curves from a series of creep curves. The simplest but not the best method for checking creep theory is to compare experimental results of relaxation under constant strain with data from creep theory.

**Discussion.**

Analysis of modern surfacing methods shows that a number of factors are characteristic of the deposited metal, which together lead to a significant decrease in the wear resistance of the applied metal coating of parts: a significant spread of mechanical properties; the presence of inclusions and metallurgical defects; heterogeneity of the structure and uneven surface hardness.
along the length of the part; the presence of unfavorable tensile stresses; reduction of fatigue strength of the deposited parts; difficulty of mechanical processing.

There are three fundamental ways in which welding strains and stresses can be reduced or eliminated, taking into account the physical nature of the processes involved in welding [16]:

1) Reducing the value of plastic deformation of shortening or the width of the zone of its propagation under heating by controlling the thermal effect in welding, reducing the heat energy, the introduction of preheating, the application of forces in welding.

2) Increasing the plastic elongation strain either during the cooling of the weld or after welding by rolling, forcing, stretching, vibration, etc.

3) Compensation by creating preliminary deformations opposite in sign to those of welding, by a rational sequence of assembly and welding.

There are many techniques to reduce or eliminate welding strains and stresses.

Ways of dealing with deformations and stresses can be divided into two groups:

1) Ways of preventing and controlling deformations.

2) Methods of eliminating deformations and stresses after welding.

The first group includes such methods which provide influence on thermal characteristics of the welding process, geometrical dimensions and shape of the structure during welding, physical characteristics and structure of the product material and weld.

**Conclusion.**

1. This paper has positively investigated the thermal process arising in the deformation zone, but does not touch the treatment of the cladding layer and investigated the characteristics of thermal processes.

2. For theoretical research, one of the stages of the surfacing process was chosen, in particular, plastic deformation of the surfacing layer by rolling with a rigid roller at elevated temperatures.

3. The dependences between deformations, stresses, speeds of their changes and time in the simplest case of uniaxial tension are established, which is called the theory of creep.

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ҚАЛҚЫМАЛЫ ҚАБАТТЫҢ ПЛАСТИКАЛЫҚ ДЕФОРМАЦИЯСЫН ЕСЕПТЕУДІҢ ТЕОРИЯЛЫҚ НЕГІЗДЕМЕСІ

Аңдатпа. Қалдық деформацияларды жою және болшектердің беттерін төсөу қезінде құрылығы жасау үшін, кеңінен пайдаланылатын әдістердің бірі - илектеу болып табылады. Металл бойлық қалдық кернеулердің әсерінен жасау үшін тігіс аймағында қалыңдығымен тұндырылады.

Айналдыру болат цилиндрлік роликермен жузеге асыribly арнайы параметрлермен жасалады: роликтін ұзатуы, ролик бөлігінің аударысы және басқа барлық қалыңдықтардың әсеріне ерекше арналған параметрлер. Қалдық деформацияларды толық жасау үшін, илектеу құрылығының тұндырылған қалыңдық деформацияларын құрылымның үйкілі есептеледі.

Ұсынылған параметрлердің есептеуін қосу арқылы жасалады. Қалыңдықтың құрылығының қалыңдығы мен деформациялардың әсерінің көбірек ұқсасынан қабылдайды. Қалыңдық деформацияларды жою үшін, ілектеу бойлық кернеулердің әсерінен тұрақтылықты жоғалтаган құрылымдың тұрқылдығы қалыңдық деформацияларын құрылымның үйкілі есептеледі.

Алмадың құрылығы қалыңдықтарға ықпал етпейтін әсеріне байланысты, қалыңдық деформациялардың әсерінің құрылығын құрылымның үйкілі есептеледі.

Қыздырылған материалдың тұндырылған қалыңдығы мен деформациялардың өзгеруінің әсерінің құрылығын құрылымның үйкілі есептеледі.

Қалыңдық деформацияларды жою үшін, ілектеу құрылығының үйкілі есептеледі.

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Теоретическое обоснование расчета пластического деформирования наплавленного слоя

Аннотация. Обкатка, это один из основных способов, наиболее часто используемых для ликвидации остаточных деформаций и обеспечения оптимальной структуры при наплавке поверхностей деталей. Обкаткой производится осаживание металла по глубине в зоне шва для создания пластических деформаций удлинения в продольном и поперечном направлениях.

Этот процесс осуществляется стальными роликами цилиндрической формы. К числу базовых параметров, описывающих данный техпроцесс, относятся: усилие во время процесса на ролик, диаметр и ширина рабочей части ролика, толщина изделия в зоне обкатки, характеристики состояния материала. Тотальное устранение остаточных деформаций получается в том случае, если создаваемые обкаткой пластические деформации удлинения в слое и соседних участках основного материала окажутся одинаковыми по значению остаточным пластическим деформациям укорочения в данных зонах. Остаточные продольные напряжения при этом могут быть равными нулю. Вместе с устранением продольных остаточных деформаций, данный техпроцесс приводит к устранению деформации конструкции, из-за потери устойчивости от воздействия продольных остаточных напряжений. Предпочтительные параметры воздействия вычисляют по приближенным формулам по схеме одноосного напряженного состояния. Для адекватного учета эффекта осаждения по толщине нагретого материала, расчета изменения остаточных напряжений и деформаций, нужно исследовать напряженно-

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деформированное состояние материала слоя, на базе которого вычисляются, также, деформирующее усилие и общая мощность. Исследован тепловой процесс образующихся в зоне деформации. Термические процессы, происходящие при наплавке деталей и поверхностной пластической деформации, имеют определяющее значение для физико-механических свойств и износостойкости поверхностного слоя и оказывают определяющее влияние на процессы и производительность пластической деформации. Также установлены температуры по длине наплавляемой детали в зоне деформации в момент отключения сварочной дуги, основанных на предположении, что температура предельного состояния наплавленной детали в зоне деформации равна температуре крайнего наплавленного валика. Как изложено выше, при увеличенных температурах расчет технологических процессов обработки металлов необходимо вести с помощью уравнений состояния простейших теорий ползучести. Наиболее общей в этом отношении является теория упрочнения. В рассматриваемом случае, в отличии от обычного процесса прокатки между врачающимися приводными валками, деформирующий ролик совершает плоскопараллельное перемещение, а на контактных поверхностях имеют место различные условия трения.

Ключевые слова. Обкатка, наплавка, температура, технологический процесс, деформация.

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