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APPROACH TO OBTAINING MEDIUM CARBON STEEL WIRE WITH A SPECIFIED SET OF MECHANICAL PROPERTIES AFTER COMBINED DEFORMATIONAL PROCESSING

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Abstract. Progressive development of metal ware manufacturing is closely connected with implementation of technologies with integrated or combined operations. Continuous method of wire deformational processing by drawing with bending and twisting was developed. Medium carbon steel wire with 0.5 %C was used for the experiments. The results of simulation in Deform-3D showed that distributions of tensile and compression stresses at combined deformational processing are uniform along the deformation zone. Microscopic analysis of the processed wire indicated that after combined deformational processing a homogeneous structure is formed in the medium carbon steel wire. After tensile test, it was proved that combination of drawing with bending and twisting allows ones to achieve the different combination of strength and ductile properties of medium carbon steel wire with one diameter and carbon content.

Keywords: medium carbon steel wire; combined deformation; drawing; bending; twisting.

1. Introduction

As a rule, different kinds of industrial technologies target only at one product manufacturing. Such state makes the choice of definite manufacturing technology and equipment for engineers rather complicated. Technological processes of metal manufacturing are based on such basic operation as rolling, drawing, pressing, stamping etc. Nevertheless, until present time the possibilities of these operations in many cases are limited in performance, rate of processing, material and energy consumption and other aspects. The rapidly changed market conditions, necessity to manufacture products in accordance with increased customer demands to metal ware properties are the key factors for industrial enterprises to find effective ways for improving technological processes of metal ware production.

One of the effective way in progressive development of technological processes is integration or combination of different technological operations. Integrated process consists in a combining more than two basic processes during which integral imposition of stresses occurs in one deformation zone. Integration rolling and pressing is used for pipe or cross-section manufacturing. Integrated rolling-drawing process during which rolling is carried out with strip end tension makes it possible to produce long-length products with complicated cross-section. Integrated rolling-forging method is used for crankshaft production. Combined process is characterized by differentiation of basic processes in time or space (place). One of the main tendency in metals processing methods is combining of casting and processes of metal deformation. Combined casting with rolling and pressing is widely used at

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metallurgical enterprises for obtaining workpieces for further sheet rolling and cross-section rolling.

Such approach allows ones to decrease the quantity of technological transitions and, hence, save material and energy sources, but also it makes the technological process more variable and flexible in accordance with market and customer demands. One can affirm that designing of technological processes with integrated and combined operations is the main tendency in metallurgy and metal ware manufacturing [1-7].

Design of integrated and combined processes needs the choice of basic operation. Basic process is a process during which during applying stress both force external distribution and its direction on the surface of plastic deformation zone do not change. As for metal ware production basic processes are casting, rolling, pressing, drawing, forging, twisting, heat treatment.

Drawing is the basic operation for wire production. This method is rather simple and is well studied both theoretically and practically. There is a great variety of equipment and tools used for manufacturing wire in wide range of diameters and cross-sections. However, at the same time drawing is the conservative process. At drawing in monolithic die the processed workpiece is effected by very tough stress-strain impact, which can not be changed or controlled. The specific stress-strain state of the processed workpiece at drawing predetermines the properties of the processed wire [8-12]. Contralateral scheme of stress-strain state of the workpiece in the deformation zone at drawing makes such conditions at which the plasticity of the processed metal is substantially lower as compared with other methods of metal processing. For improving wire plasticity, it is necessary to use intermediate heat treatment operations in the technological process of wire production especially for wire with less than 1 mm in diameter.

Level of wire mechanical properties and microstructure changing after drawing depends to high extent on the chemical composition and properties of the processed workpiece, deformation degree, drawing rate, die geometric dimensions and other parameters [13-19]. At recent time attention of engineers is devoted to combined processes for wire manufacturing. It was shown that combination of drawing with different kinds of deformation (twisting, tension, compression, bending) makes it possible to increase the drawing process efficiency, decrease material consumption of the equipment, change the stress-strain state scheme to more favorable which ensures higher plasticity and high level of mechanical properties of the wire [20-25].

In most cases, designing of the combined processes needs special equipment or tools. This factor limits implementation of such methods at industrial level. On the other hand, each kind of deformational processing influences microstructure and mechanical properties of the workpiece. This effect becomes more complicated at combination of different kinds of deformation. From this point of view, it is necessary to investigate the peculiarities of microstructure and mechanical properties formation during combined deformational processing [26,27]. The aim of this paper is to study the continuous method of wire deformation processing which represents the combination of drawing with bending and torsion. Such combination makes it possible to change wire mechanical properties in a wide range that is very useful for different areas of customer applications.

2. Methodology

Medium carbon steel wire as one of the widely used metal ware product for different applications was chosen for the experiments. It contained 0.5 % C (0.5 %C - 0.2 %Si – till 0.6 %Mn - till 0.25 %Cu - till 0.08 %As - till 0.25 %Ni - till 0.040 %S - till 0.035 % %P - till 0.25 %Cr - in wt. %). Its diameter was 3.45 mm. For combination of drawing with bending and twisting the laboratory setup was constructed (Fig. 1).

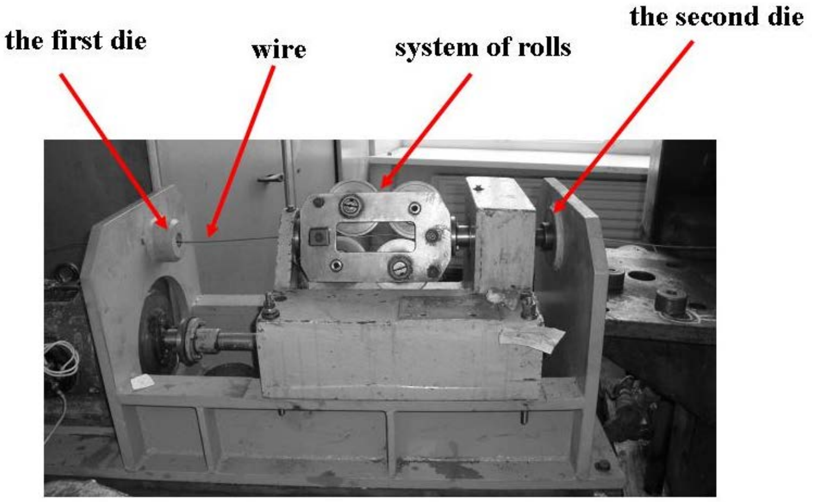


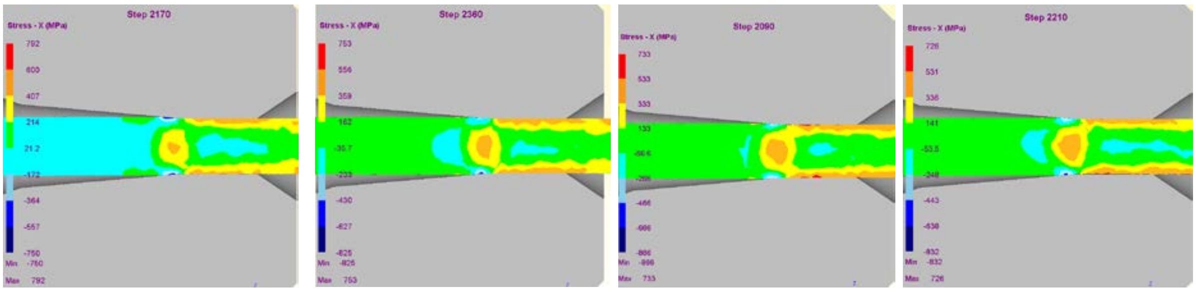
Fig. 1. Laboratory setup for combination of drawing with bending and twisting.

It consists of two consequently arranged along the longitudinal symmetrical axis dies with four rolls system placed between them. Dies are toughly fixed inside the frame. The wire axis is aligned with the drawing direction. The four rolls are joined together in one block. Rolls are fitted with the possibility to rotate while wire moving. Such arrangement of dies and the four rolls block results in applying to the moving wire combination of drawing with bending and twisting. Four rolls system has autonomous engine, which enables the rotation of the block [28-30]. The designed construction of the setup allows changing deformational impact on the processed wire in wide range, for example varying reduction in dies, the rolls diameter and rotation rate of the system of rolls. The construction if this setup and method for its application for carbon steel wire deformational nanostructuring are defended by patents of the Russian Federation [31, 32].

For the experimental part, the deformation ratio in dies was chosen depending on the wire mechanical properties in as received state. In order to study the effect of deformation degree on mechanical properties of the processed wire total deformation degree was 18.70 %, 26.77% and 35.47 % without changing rolls diameter (90 mm). The rate of twisting changed from 0 to 150 RPM (revolutions per minute) and mineral soap was used as the lubricant. The microstructure observations were carried out by a Leica Cambridge Stereoscan 440 scanning electron microscope (SEM) in University of Padova. Samples for metallographic examination were prepared from the deformed wire by etching. Tensile test was carried out in accordance with ISO 6892-1:2009(en) «Metallic materials - Tensile testing - Part 1: Method of test at room temperature».

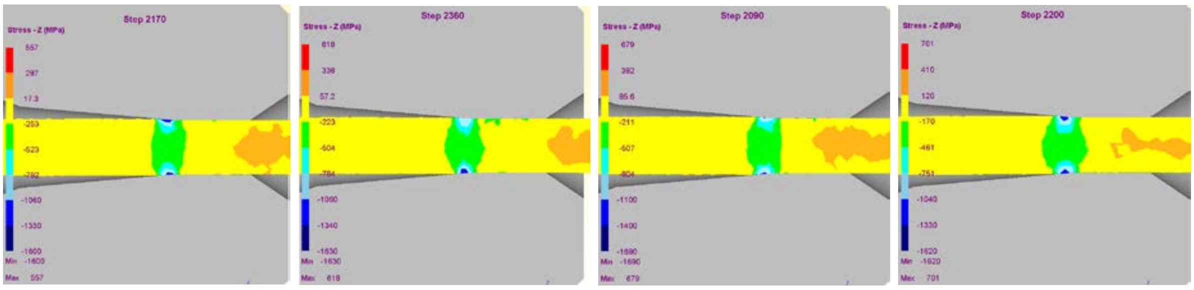
3. Experimental results and discussion

In order to determine the stress-strain state of the workpiece at combined deformational processing by drawing with bending and twisting the simulation in software Deform-3D was used. For simulation the initial conditions were the following: deformation in dies and rolls diameters were constant while the rate of twisting varied from 0 till 150 RPM. In Fig. 2 tensile and compression stresses distributions in the processed workpiece along the deformation zone in die are presented.



0 RPM 50 RPM 100 RPM 150 RPM

a



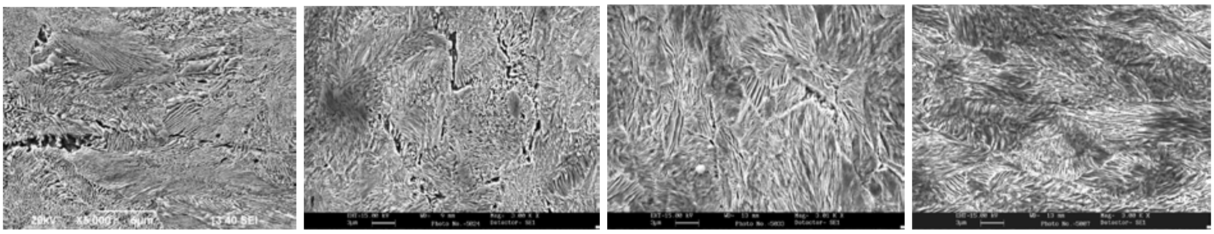
0 RPM 50 RPM 100 RPM 150 RPM

b

Fig. 2. Tensile and compression stresses distributions in the processed medium carbon steel workpiece with 0.5%C along the deformation zone at combined deformational processing by drawing with bending and twisting: a - tensile stress; b - compression stress.

With increasing twisting rate the level of tensile and compression stresses increases but they are not so high to cause the breakage of the processed workpiece. The results of simulation show that with increasing of twisting rate the tensile and compression stresses distributions along the deformation zone become uniform. One can conclude that using the rate of twisting 150 RPM is more preferable for combined deformational processing by drawing with bending and twisting.

The microstructure of medium carbon steel wire with 0.5 %C after different kinds of deformational processing was observed. In as received state, after drawing, the microstructure consists of ferrite-carbide mixture and low quantity of structural free ferrite, which locates in the form of individual separate areas along the boundaries of pearlite colonies (Fig. 3).

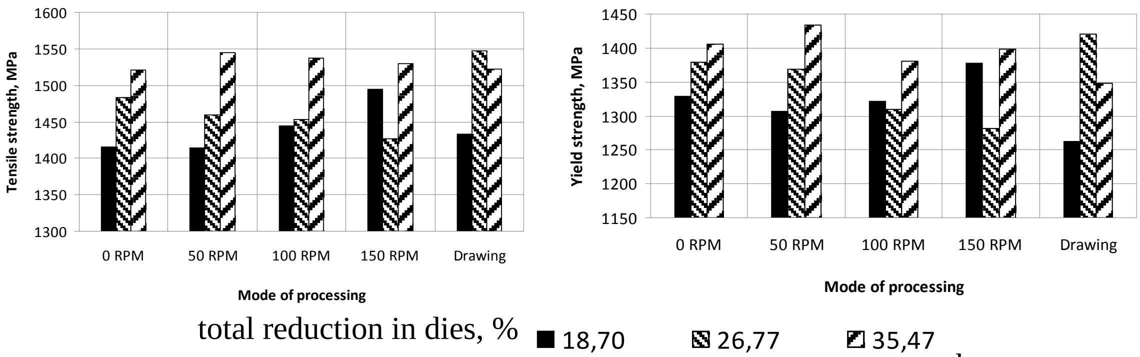


a b c d

Fig. 3. Microstructure of medium carbon steel wire with 0.5%C after different kinds of deformational processing: a - as received state; b – drawing; c - drawing with bending; d - drawing with bending and twisting.

After combined deformation by drawing with bending, the pearlite colonies rotate along the deformation axis (Fig. 3). The lamellar structure of pearlite continue to exist. Inside the pearlite colony parallel structure is observed and carbide phase has plate form. During combined deformation there is an incentive to reorientation under outer loading in these areas wherein carbide morphology changes, cementite plates start to bend and crash. After imposing on the carbon steel wire twisting with 150 RPM (see Fig. 3) the same tendency in microstructure changing can be denoted in combined deformational processing by drawing with bending and twisting as at drawing with bending. However, elongation and rotation of the pearlite colonies along the deformation axis is more effective. After this combined deformational processing, the plate structure of pearlite is broken.

Mechanical properties of the processed medium carbon steel wire with 0.5 % C after different combination of deformation are presented in Fig. 4.



a b

Fig. 4. Mechanical properties of medium carbon steel wire with 0.5%C after different kinds of deformational processing and different total reduction in dies:
a – tensile strength; b – yield strength.

The results show that mechanical properties of the processed carbon steel wire change in wide range depending on applied deformation or their combination and at the same time deformational parameters also affect the level of mechanical properties. As compared with drawing, the wire tensile strength is higher after combined deformational processing only at lower total reduction in dies. With increasing total reduction in dies the wire tensile strength also increases but its level may be lower or the same as after drawing. Combined deformational processing by drawing with bending and twisting leads to increasing wire yield strength as compared with drawing when total reduction in dies are lower or higher. It is obvious that applying definite deformational parameters one can achieve medium carbon steel wire with high strength and ductility without using interoperation heat treatment. Such variety of wire mechanical properties is very useful for practical application of this approach because the manufacturer can easily adapt the deformational processing in accordance with customer demands and broaden areas of applicability of the processed wire.

4. Conclusions

Integrated and combined technologies is the perspective way for metal ware production. Such approach allows to decrease the quantity of technological transitions and, hence, save material and energy sources. Continuous method of deformational wire processing by drawing with bending and twisting was designed. The advantages if this method consists in arrangement the tools which are used in industrial technologies for wire and rope production. Combination of drawing with bending and twisting makes it possible to obtain medium carbon steel wire with wide variety of tensile strength and yield strength. Applying definite deformational parameters one can achieve medium carbon steel wire with high strength and ductility without using interoperation heat treatment. Implementation of the developed method offers new opportunities for science-driven technology which can be easily adapted to customer demands.

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