

## Alternate drawing as the way for improving mechanical properties of medium carbon steel wire

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**Abstract.** Drawing in monolithic dies is the basic operation of wire manufacturing. Despite the obvious advantages the drawing in monolithic dies is characterized by relatively tough stress-strain scheme of the processed wire which results in decreasing of its plasticity. During alternate drawing the wire goes through the conical die after which the drawing direction is changed. The results of investigation of alternate drawing process of medium carbon steel wire with 0.5 %C are presented in the paper. After simulation in software Deform-3D it was stated that strain intensity distributes uniformly across the wire transversal cross section. Using coordinate grid method the data about the metal flow both at traditional and alternate drawing was obtained. Results of carbon steel wire mechanical properties investigation proved the advantages of alternate drawing process. After alternate drawing the medium carbon steel wire possesses high plasticity at the same level of strength properties as compared with traditional drawing process. At the same time there were no considerable changings of medium carbon steel microstructure after alternate drawing.

### 1. Introduction

Wire manufacturing takes the first place in the whole volume of metal ware production. Steel wire can be used both as the final consumer product (for example, string wire, needle wire, polygraphic wire etc.) and as the semiproduct for mesh, electrodes, cables and ropes production etc. Technological process of wire manufacturing consists of several traditional operations: descaling and surface preparation before drawing, drawing to the definite diameter, thermal treatment and final processing operations. Basics tendencies in industrial wire manufacturing are the following: increasing the capacity of equipment with maximum saving of technological process current, decreasing of both basic and nonproduction material and energy sources, increasing strength and plastic wire properties, enhancement of manufacturing of new wire types with improved customer properties.

Drawing in monolithic dies is the basic operation of wire manufacturing. Despite the obvious advantages the drawing in monolithic dies is characterized by relatively tough stress-strain scheme of the processed wire which results in decreasing of its plasticity especially at multiple drawing. Frequently high-strength wire is rejected exactly because of untimely loss of plasticity and exfoliation. One of the main reasons of these effects is the high level of residual stresses in wire which formed after drawing. Especially frequently it is observed on the wire with large diameter [1]. From this point of view one of the main tendency both in theoretical and practical investigations is the choice of new approaches for drawing process development which allow to preserve the plasticity reserve in the processed wire.

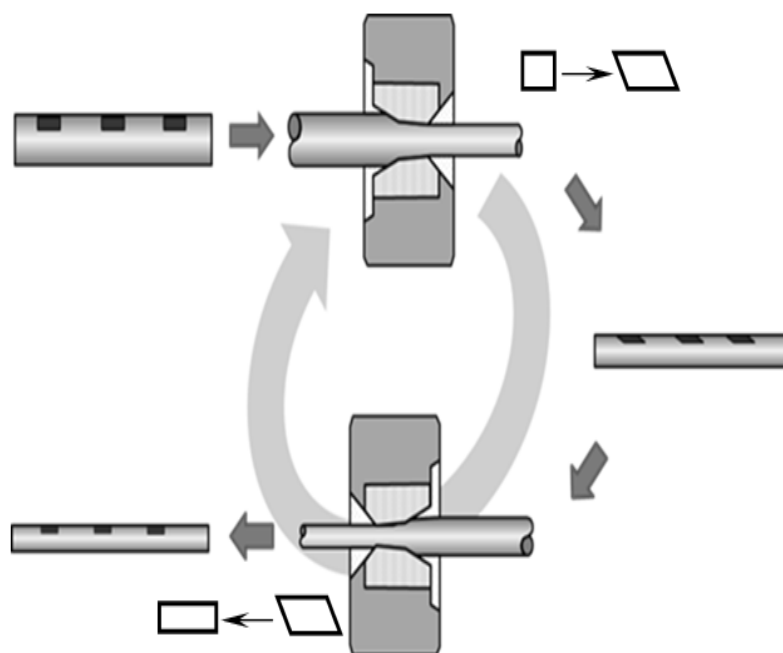


Combined and integrated processes which are designed in the basic operation of drawing make it possible to solve this problem [2-4]. Advantages of these technologies consist not only in the reduction of technological operations in the manufacturing process and, hence, energy- and material saving, but also they allow to achieve the product with new complex of properties [5, 6]. But in most cases designing of such processes demands the construction of special instruments and tools, using special approaches for concordance of the processing speed on different parts of the wire for ensuring the process continuity which in total to high extent limits the implementation of such processes in the industrial wire manufacturing technologies. From this point of view finding of new methods for traditional wire drawing which make it possible to preserve its plasticity reserves is the actual task.

It was shown in [7-13] that after alternate drawing the wire have high level of strength and plastic properties. The essence of this method consists in the drawing the wire through the conical die after which the drawing direction is changed. Such method of processing is characterized by low level of share deformation near the wire surface which saves its high plasticity. It was proved experimentally on the wire from nonferrous metals and alloys and high carbon steel. In order to get knowledge about this type of drawing it is reasonable to study the peculiarities of alternate drawing of wire made from steel with another carbon content.

## 2. Methodology

The aim of this investigation is to test the method of alternate drawing (figure 1) on medium carbon steel wire grade 50 (0.5 % C) with 4.0 mm in diameter, which chemical composition is presented in table 1. For the experiments medium carbon steel wire was used in as received state.



**Figure 1.** Alternate drawing process [10].

**Table 1.** Chemical composition of steel grade 50.

Steel grade	Element content, %									
	C	Si	Mn	Ni	S	P	Cr	Cu	As	Fe
Grade 50	0.47 - 0.55	0.17 - 0.37	0.5 - 0.8	till 0.25	till 0.04	till 0.035	till 0.25	till 0.25	till 0.08	~97

In table 2 experimental technological parameters of wire processing by alternate drawing are presented.

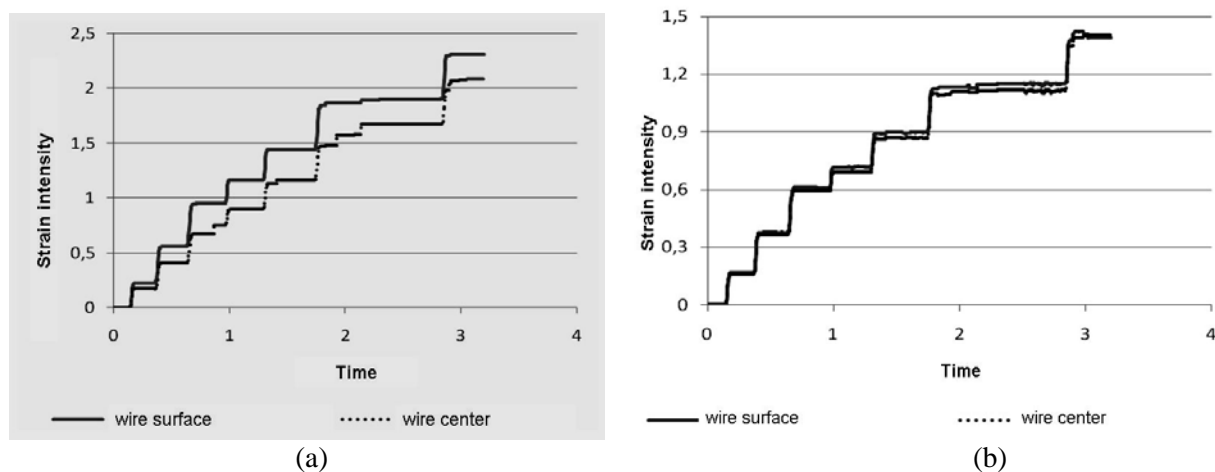
**Table 2.** Parameters of alternate drawing of medium carbon steel wire grade 50.

Die diameter $D$ , mm	3.71	3.37	3.05	2.82	2.59	2.3	2.00
Reduction degree in die $\varepsilon$ , %	13.97	17.48	18.08	14.51	15.64	21.14	19.56
Total deformation degree, %	13.97	29.01	41.85	50.29	58.07	66.93	75

Alternate drawing was carried out on the laboratory single-stage drawing mill. Mineral soap was used as the lubricant. 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. Results and discussion

Finite-element simulation in the software Deform-3D was carried out for investigation the regularities of metal flow at alternate drawing. Strain intensity distributions at different kinds of drawing of medium carbon steel wire grade 50 with 4.0 mm in diameter are presented in figure 2.

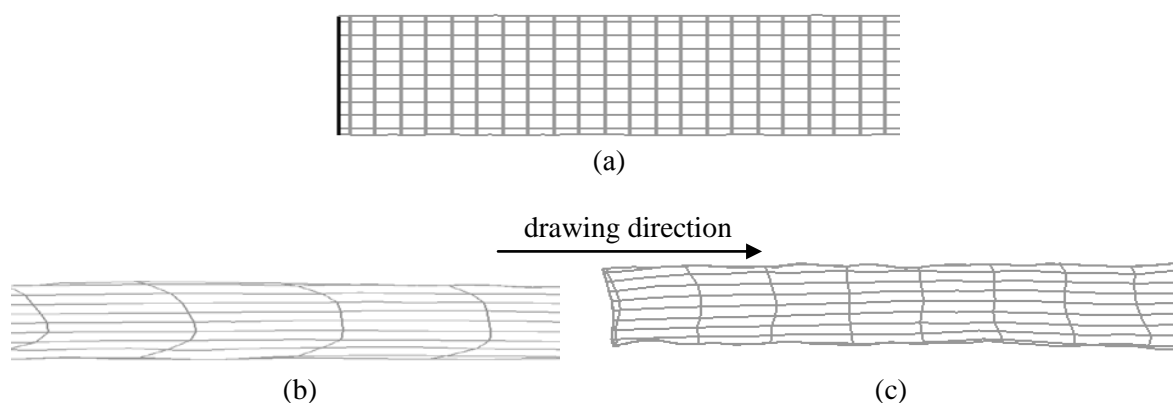


**Figure 2.** Strain intensity of wire from steel grade 50 at traditional drawing (a) and alternate drawing (b).

Results of simulation show that at alternate drawing because of changing drawing direction strain intensity distributes uniformly across the whole wire. At the same time strain intensity has different quantitative meanings: it is lower at alternate drawing. This is one of the essential factors which ensures the preservation of wire plasticity.

Using grid method the data about metal flow at traditional and alternate drawing was obtained (figure 3).

As one can see, because of applying pulling force to the wire front end (drawing force) the coordinate grid lines elongate along the drawing direction resulting in formation of typical drawing texture, i.e. grains elongate along the drawing axis. In table 3 coordinate grid geometrical parameters obtained by metal flow simulation of different types of drawing of wire from steel grade 50 with 4.0 mm in diameter are presented.

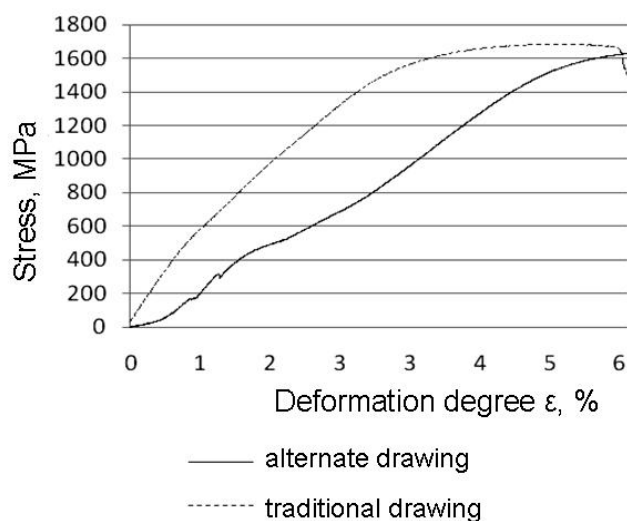


**Figure 3.** Coordinate grid changing on the longitudinal wire cross section: (a) original grid; (b) coordinate grid after traditional drawing; (c) coordinate grid after alternate drawing.

**Table 3.** Coordinate grid geometrical parameters changing obtained by simulation of metal flow at traditional and alternate drawing of wire from steel grade 50 with 4.0 mm in diameter.

Wire diameter, mm		4.0	3.71	3.37	3.05	2.82	2.59	2.3	2.0
Cell length $L$ , mm	traditional drawing	0.18	0.18	0.3	0.77	0.81	1.16	1.5	1.92
	alternate drawing	0.18	0.18	0.36	0.63	0.35	0.45	0.38	0.20
Angle of coordinate mesh vertical line $\alpha$ , grad.	traditional drawing	0	3.54	6.8	8.5	13.5	19.94	33.6	39.9
	traditional drawing	0	6.91	7.11	7.84	5.88	5.30	4.15	2.60

After tensile test of medium carbon steel wire grade 50 after different types of drawing it was found that after alternate drawing the processed wire possessed high plasticity at the same level of strength as after traditional drawing (figure 4). In table 4 mechanical properties of medium carbon steel wire grade 50 after different types of drawing are presented.

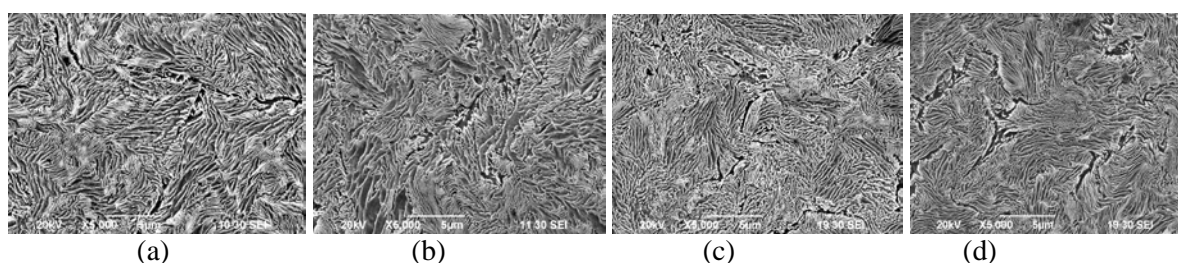


**Figure 4.** Load-extension diagram of medium carbon steel wire grade 50 after traditional and alternative drawing.

**Table 4.** Mechanical properties of medium carbon steel wire grade 50 after traditional and alternative drawing.

Method of deformational processing	Ultimate tensile strength $\sigma_s$ , MPa	Yield strength $\sigma_{0.2}$ , MPa	Relative elongation $\delta$ , %
Traditional drawing	1677	1142	1.55
Alternate drawing	1660	1259	1.77

Results of mechanical tests of medium carbon steel wire grade 50 proved the advantages of alternate drawing: yield strength increases to 9,3 %; relative elongation increases to 12,4 %. At the same time considerable changes in microstructure of medium carbon steel wire after traditional and alternate drawing are not observed (figure 5).

**Figure 5.** Microstructure of medium carbon steel wire grade 50 after traditional (a, b) and alternate (c, d) drawing: surface area (a, c), central area (b, d).

#### 4. Conclusion

For preservation of plasticity reserve of carbon steel wire at drawing it is expediently to use such methods which make it possible to reduce the strain unevenness. During alternate drawing the drawing direction is changed resulting in decreasing strain unevenness in the processed wire. On medium carbon steel wire it was proved experimentally that after alternate drawing plastic properties increase with saving the same level of strength as after traditional drawing. The obtained results are promising for further implication of alternative drawing to the industrial technologies of wire manufacturing for obtaining the metal product with improved level of customer properties.

#### Acknowledgments

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