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Combined Method of Precipitation-Hardening Alloy ЭП - 543 Strengthening in Elastic Wires

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The results of investigation of strength and plastic properties of high-strength precipitation-hardening alloy ЭП - 543У (ХН40МДТЮ) after cold drawing and subsequent heat treatment are presented. Efficiency of static and dynamic ageing for improvement of screw elastic wire quality is shown.

Keywords: WIRE, DRAWING, COMPRESSION SPRINGS, HARDENING, AGEING, STRENGTH, PLASTICITY, QUALITY

Introduction

It is known [1] that operational durability of elastic elements raises with the growth of strength properties. It is possible to achieve high strength due to high extents of metal cold strain. However, excessive deformation can complicate the process of billet production because of fracture. Besides, metal can fracture when producing elastic elements including plastic forming of hammer-hardened billet. It is mentioned in [2] that high breakage of ЭП - 543У (ХН40МДТЮ) alloy wire is observed during cold drawing at large total deformations (more than 75 %).

Investigations [1, 3, 4] determined the efficiency of precipitation-hardening alloy strength improvement due to strain hardening with the subsequent strain ageing, heat treatment of springs when free and under loading.

The task of research is to show reasonability of combined method of ЭП - 543У alloy hardening in the wire compression springs.

Methodology

High-strength nickel-based alloy ЭП - 543У developed by Central Iron and Steel Institute for Scientific Research [5, 6] has the following chemical composition, % by weight: C ≤ 0.04; Si, Mn ≤ 0.80; Cr = 14.0-17.0; Ni = 39.0-42.0; Ti = 2.5-3.2; Al = 0.7-1.2; Mo = 4.5-6.0; Cu = 2.7-3.3; S ≤ 0.020; P ≤ 0.035; Fe - the rest. The alloy has raised corrosion cracking resistance in sulfuric acid solutes, technological solutes of oxygen compounds of chlorine as well as medium containing hydrogen sulfide and carbonic gas.

Results and Discussion

Springs are fixed in the borehole equipment applied for oil and gas recovery. During operation the springs are in compressed position and not isolated from effect of corrosive environment containing hydrogen sulfide, carbonic gas, chloride. The temperature can reach 200 °C which promotes the stress relaxation and creep flow processes. As a result, the springs change geometrical sizes and loading characteristics.

Effect of amount of ЭП - 543У alloy wire reduction at cold drawing λ on the mechanical properties is shown in **Figure 1**: rupture strength σ_r, conventional yield strength $\sigma_{0.2}$, contraction ratio ψ, number of torsions n_{tor} and bends n_b before fracture. We drawn a billet quenched in water from 1050 °C. We used powdered soap with sulfur addition as a lubricant.

An average amount of reduction on wire cross-section during drawing is determined by formula [7]:

$$\lambda = 2\sqrt{3}\ Ln\,(d_0/d_1) + \sum_{i=1}^{n} tg\,(\alpha_i) \qquad \text{(Eq. 1)}$$

where α_i - semiangle of working cone i - drawing die (for drawing we used drawing dies with semiangle of working cone 6 °). It follows from **Figure 1** that mechanical properties of ЭП - 543У alloy wire change during drawing in the same way as for 8-18 stainless steel wire [8]. Intensity of alloy hardening considerably decreases at deformation 1.5-2.0 and above. To determine the effect of strain ageing on mechanical properties of alloy, the wire with various amount of reduction is subjected to soaking for 0.5-8 hours at 200-800 °C. Results of investigation of contraction ratio and rupture strength depending on strain ageing regimes are presented in **Figure 2**.

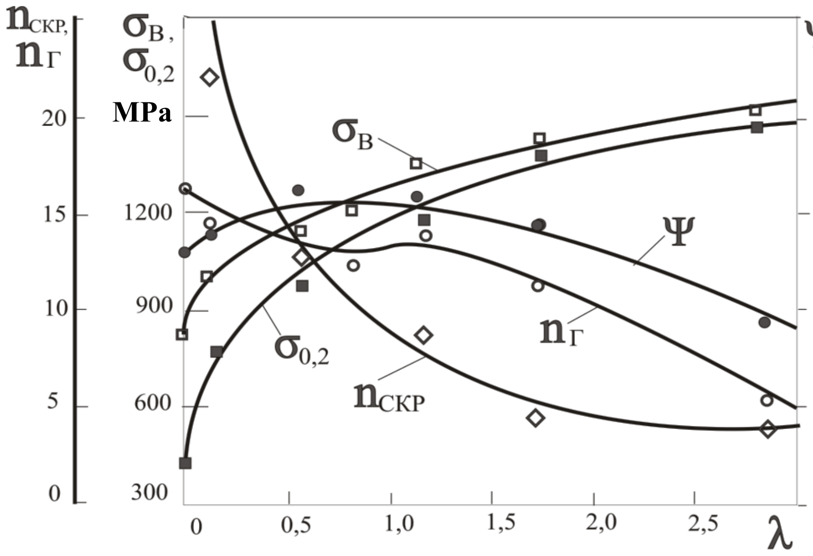

Figure 1. Dependence of mechanical properties of ЭП - 543У alloy wire on amount of reduction

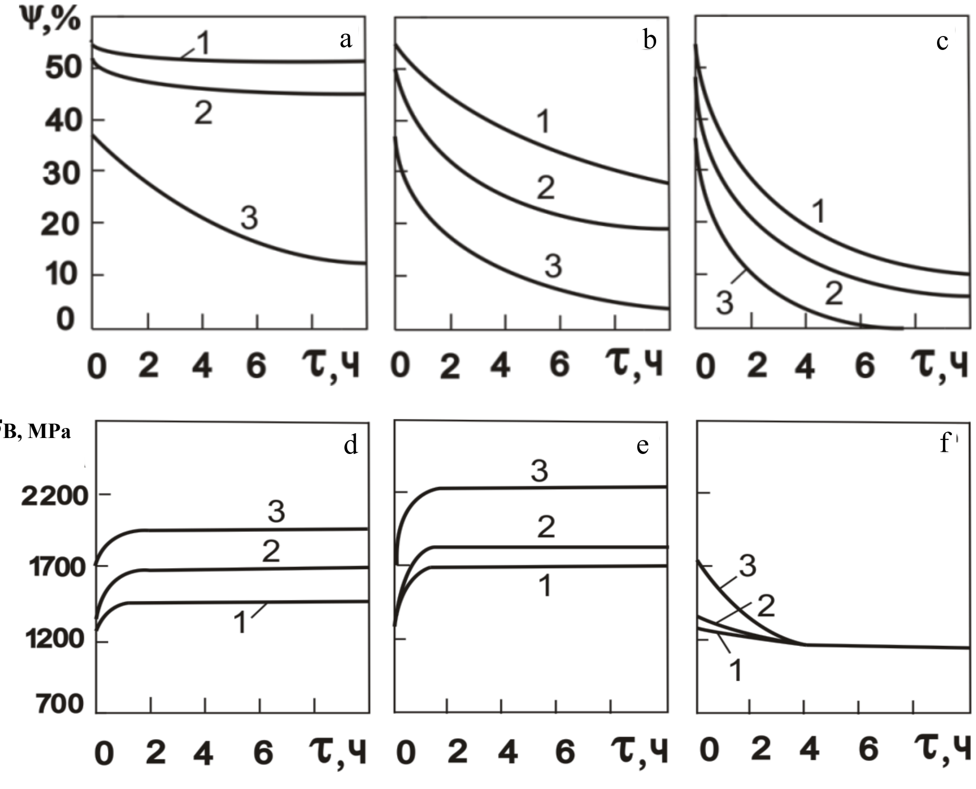

Figure 2. Effect of amount of reduction, temperature and aging treatment time on contraction ratio (*a*-*c*) and rupture strength (*d*-*g*) of ЭП - 543У alloy wire: *a*, *d* - 450 °C; *e* - 650 °C; *c*, *f* - 800 °C; *1* - λ = 1.27; *2* - λ = 1.50; *3* - λ = 1.50

As we can see, amount of reduction has a considerable effect on the pattern of mechanical properties change in the process of ageing. The increase in amount of reduction promotes strengthening of strain ageing effect. At strain ageing of hard-wrought alloy the hardening occurs because of precipitation of γ' - phase of type $Ni_3(Ti, Al)$ in γ - solid solution [1].

Gain of strength properties is insignificant at ageing temperature 450 °C. More substantial strength improvement with certain loss of plastic properties is observed at ageing temperature 650 °C. At 800 °C alloy is overaged which leads to simultaneous loss of strength and plastic properties of the wire.

It is determined in [5] that alloy weakening starts approximately from 700 °C and temperature of maximum hardening is moved towards smaller temperature area with increase in extent of wire cold strain. At alloy overageing the structure changes: precipitations of hardening γ' - phase in γ - solid solution are merged in the form of irregular shape particles (**Figure 3c**), as a result strength and plastic properties of alloy get worse.

At lower temperatures of tempering (**Figure 3b**), when alloy is underaged, the hardening phase is fine-dispersed, and the structure does not differ from cold-wrought wire structure.

Springs are treated by three regimes: a) no heat-treatment after springs coiling; b) after coiling springs are subjected to age-hardening when free (static ageing) and c) ageing in compressed condition (dynamic ageing). Both ageing regimes are carried out at 450 °C for 30 minutes. The value of spring compression at dynamic ageing is 20 %.

As the springs are fabricated we measured their initial height h_0 by calliper with accuracy 0.1 mm and estimated stability of their geometrical sizes. We tested five springs after each treatment schedule. The residual compression of the spring is computed by formula:

$$\Delta h = \frac{h_o - h_1}{h_o} \cdot 100\%, \qquad \text{(Eq. 2)}$$

where h_1 - spring height after hardening at 200 °C.

Dependences of residual compression of the spring produced by various regimes depending on duration of hardening are illustrated in **Figure 4**.

Cold-drawn wire springs without further heat treatment gained a considerable residual compression which is inadmissible at their maintenance. Alloy ageing when free and in the stressed condition reduces the negative effect of amount of reduction on stability of spring geometrical parameters. And higher dimensional stability of springs is observed after dynamic ageing. This is possible to explain by enhancement of elastic properties of alloy due to precipitation hardening under conditions of internal stress effect.

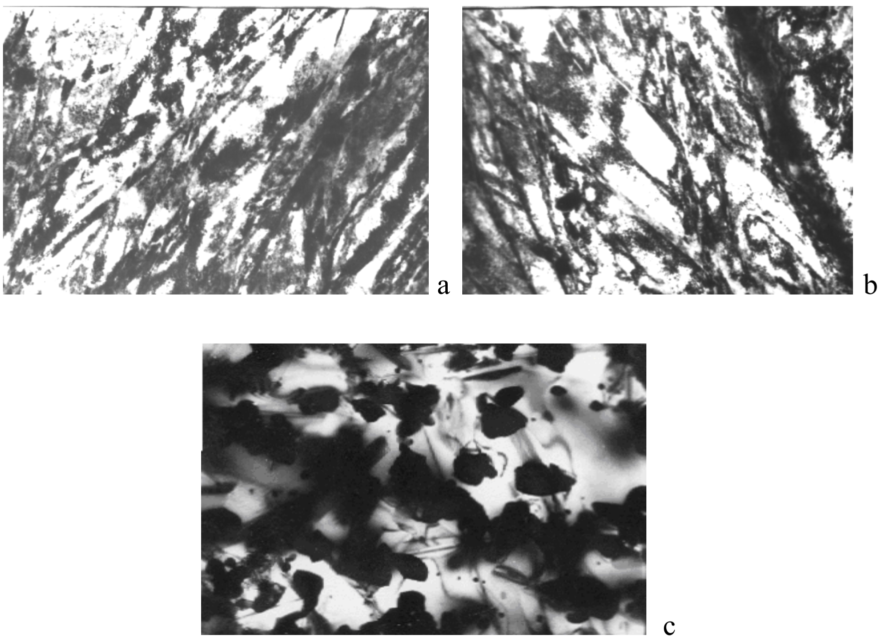

Figure 3. Microstructure of cold-wrought ЭП – 543 У alloy wire, thin foil method, × 15000: *a* - before ageing; *b* - after ageing at 600 °C, 6 hours; *c* - after ageing at 800 °C, 6 hours

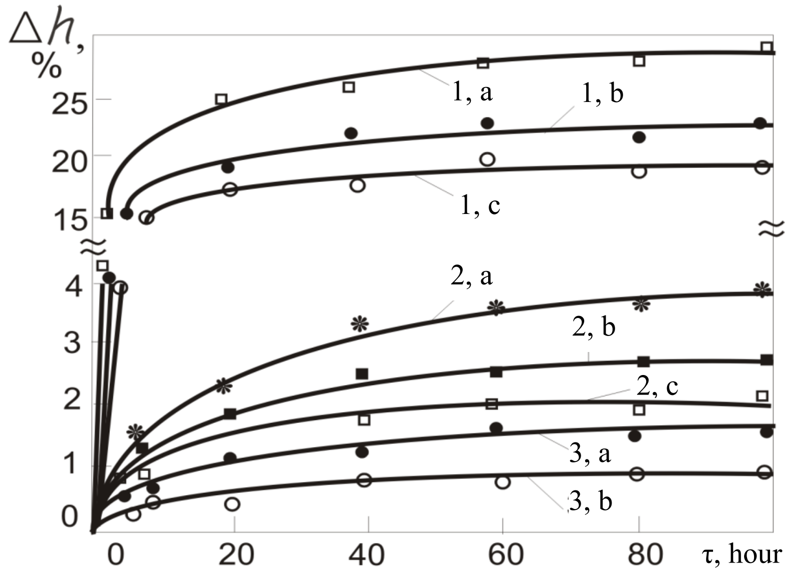

Figure 4. Dependence of spring residual compression Δh at 200 °C on hardening time: *1* - cold-drawn wire spring; *2* - spring after static age-hardening; *3* - after dynamic age-hardening at upsetting on 20 % (*a* - λ = 2.65, *b* - λ = 1.50, *c* - λ = 1.27)

It is necessary to note that dynamic ageing has a positive effect on spring quality during production from quenched alloy when there is no deformation mechanical hardening [4].

Conclusions

Results of investigation show that age-hardening is necessary after coiling of cold-drawn wire springs. Dispersion hardening of alloy at age-hardening enhances the strength properties of alloy. The temperature of age-hardening should not be above 700 °C as at higher temperatures the alloy softens and has low plastic properties. Springs after dynamic age-hardening have higher quality. Such treatment is reasonable when producing springs with high requirements to their stability of geometrical and loading characteristics.

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Комбинированный способ упрочнения дисперсионно - твердеющего сплава ЭП – 543У в проволочных пружинах

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Приведены результаты исследования прочностных и пластических свойств высокопрочного дисперсионно - твердеющего сплава ЭП – 543У (ХН40МДТЮ) после холодного волочения и последующей термической обработки. Показана эффективность проведения статического и динамического старения для повышения качества винтовых проволочных пружин.