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RELATION BETWEEN ANOMALIES OF FERRUM PHYSICAL PROPERTIES AT ~650 °C WITH POSSIBLE TRANSFORMATION IN IT

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ABSTRACT

According to the researches by G. Tamman, E. Gudremon, A. A. Bochvar, A. M. Samarin and B. G. Livshits, any property is suitable for detecting of transformation: bending or extremal value on a curve. Transformations in ferrum at the temperature below 700 °C have been discussed many times. V. S. Meskin denies transformation at the temperature below 700 °C without any references, but at the same time he refers to the data by G. N. Mekhed and A. Sover that testify about the contrary conclusions (minimal values of ψ and number of torsion twistings at 600 °C).
The paper presents analysis of extremal values on the curves (strength of upsetting resistance, parameters of fine structure and metallographic structure) in dependence on temperature, as well as multiple literature data on anomalies of physical and mechanical properties if ferrum and steels. Based on the above-mentioned, transformation at ~650 °C is declared.
Recognition of transformation at the preset temperature is one of the ways allowing to formulate the version of the nature of embrittlement of forged (P. Oberhoffer) or quenched (E. Gudremon) or cold-worked (E. Gudremon, G. A. Kashchenko) steel after tempering (annealing) at the temperature above ~ 650 °C. Other variants of considered metal post-treatment are presented by isothermal austenite transformation (M. Gensammer) and gigantic diffusion (Yu. I. Ustanovshchikov) at the same temperature as well as a “wonderful fact” of transformation in pearlite during seconds at the temperature 670 – 630 °C (V. M. Schastlivtsev).

Introduction

The aim of this work is substantiation of the relations between the extremal values on the curves of ferrum physical and mechanical properties with transformation in it at the temperature ~650 °C. This transformation can determine anomalies of mechanical properties also of steels as ferrum derivative.

The term “Transformation” can be explained on the Fe example. Both transformations at A_2 (so-called magnetic) and A_3 (so-called polymorphic) are the thermal ones, they are accompanied by thermal effects and anomalies of properties: peak of heat capacity, diffusion acceleration, bending of thermo-emf curve (at A_2 temperature) and compression during heating, minimal value of thermo-emf, archi-brittleness under impact, peak of creep flow (at A_3 temperature). It should be noted that “there is no common opinion about the causes of polymorphism at A_3 temperature” [1], but “theoretical model of ferro-magnetism” is “quite approximate” [2]. Thereby the term “transformation” means variation of interaction between Fe atoms that causes anomalies of properties and steels as ferrum derivative.

The conditional temperature ~650 °C is accepted in the current work because it corresponds to the data in the table on the p. 125, but not to the figure built on its base on the p. 126 (600 °C) [3]. The authors are sure that the results of this reference link allow to conclude that transformation occurs at the temperature ~650 °C (more precisely — in the range 600–700 °C).

Technique

Upsetting force *P* for half-height deformation of samples made of ferrum (0.008% C) with diameter 10–15 mm has been determined on the “Gleeble-3800” unit. Heating up to deformation temperature has been conducted by passage of electric current with heating rate 5 °C /s. Then the following operations have been executed: deformation with rate 0.5 s^{-1}, golding during 1 min and free cooling via heat transfer in water-cooled copper clutches.

X-ray structural analysis has been done on diffractometer of general usage (DRON-2) on the ferrum samples containing 0.008% C with cubic form with size 10×10×10 mm.

The technique is based on the following opinions of the researchers: “When searching phase equilibrium, you can use any properties” (B. G. Livshits); “You can choose any of about 50 properties used at present time in physical-chemical analysis as structurally sensitive properties” (A. A. Vertman, A. M. Samarin); “ It is possible to take hardness,..., electric conductivity,..., density,..., coefficient of linear expansion etc. as measuring physical property” (A. A. Bochvar).

Analysis of literature data

Transformations in metals and alloys can be revealed through the trip-effect (or via DIT-effect, where DIT is ductility induced by transformation).

Trip-effect is manifested in harsh increase of relative elongation [4]. Thereby relative elongation (δ) can exceed relative narrowing (ψ) [4]; usually ψ > δ.

E. M. Savitsky has displayed the evident anomaly of ferrum mechanical behaviour (0.025% C): δ is larger than ψ at the testing temperature 600 °C: they make ~40% and ~38% respectively [3].

The testings have been conducted at 12 different temperatures (20–1100 °C, with pace each 100 °C), but δ (~75%)

exceeds ψ (~70%) still at 900 °C; at other temperatures the relationship between δ and ψ is usual: δ < ψ.

Anomaly of ductility (δ > ψ) at 900 °C can be explained by DIT-effect because the indisputable phase transformation $\alpha \leftrightarrows \gamma$ in ferrum occurs near this temperature.

The same anomaly of ductility (δ > ψ) is observed in the following cases: in calcium at 350 °C [3], when polymorphic transformation is evident; in metastable austenite steels where polymorphic $\gamma \rightarrow \alpha$ transformation in deformation marten site is observed during extension in the interval of martensite transformation [4]; in steels 35 and 12KhN3A (12 ХН3А) during extension in the intercritical range A_1–A_3 (at the temperature ~740 °C), when polymorphic transformation austenite ⇆ ferrite occurs (δ exceeds or is almost equal to ψ) [5]. It should be noted that in last mentioned steels ferrite contains ~0.02% C at ~740 °C, as ferrum described by E. M. Savitsky [3].

The same mechanical behaviour of the listed materials and ferrum at 600 and 900 °C (meaning their quality) allows to suggest action of the DIP-effect in ferrum at at 600 °C, i.e. transformation in ferrum at this temperature.

The same conclusion can be done after observation of the temperature relationship of dynamical ductility (ε_{dyn} — sample shortening during impact upsetting). If we draw the curve along the experimental points, ε_{dyn} practically does nor depend on the temperature in the intervals 20–600 and 900–1100 °C , but it rises abruptly (by ~2.5 times) in the temperature interval 600–900 °C [3]. It creates bends of the curve at 900 and 600 °C, i.e. near indisputable transformation and transformation proposed in this work.

Let's examine ferrum physical properties.

The rate of increase of "the value of internal stresses arising in armco iron during heating" above 600 °C is higher by 3 times than in the temperature interval 300–600 °C [3].It means bend of the curve at 600 °C. According to G. Tamann and E. Gudremon [6], such bends of the curves testify on transformation. The same bend of the curve of electric resistance can be observed at ~600 °C, while in the interval from ~600 °C to A_2 temperature the linear relationship is revealed [7].

The other arguments in favour of presence of ferrum transformation at the temperature ~650 °C are listed:

• maximal value on the curve describing temperature dependence of Lorenz number at ~600 °C and minimal value — at ~670 °C [8];

• maximal value on temperature dependence of the coefficient of linear expansion at ~650 °C [6];

• bend of the curve describing temperature dependence of heat capacity at ~650 °C [9], [10];

• bend of the curve describing temperature dependence of heat conductivity (data by Shelton) at 600 °C, and this curve stops its decrease in the temperature interval 600–700 °C [2];

• maximal value of magnetostriction in the field 900 oersted at ~650°C [11];

• bend of the curve of maximal magnetic penetration at ~650 °C [11];

• small but apparent increase of the growth rate of heat contents and the lattice parameter (data by Schmidt) during heating above ~650 °C [12].

Declared transformation in ferrum at ~650 °C has been established (on the authors' opinion) still in 1886 by Pionchon: to heat ferrum above 660 °C it is required "essentially more calories" [1], than to heat it below 660 °C. "The Pionchon's conclusions have been confirmed by Le Chatelier in the same year, when he has examined principally another appearance" [1] (thermoelectric power of the pairs containing ferrum).

Transformation at ~650 °C can be connected with so-called "wonderful fact" [13]: "forming of ferrite plates (containing 0.02–0.015% C) and cementite plates (containing 6.67% C) are formed in the process of eutectoid transformation of eutectoid steel from the high-temperature phase during only during several seconds" [13].

This reaction occurs in the "narrow temperature interval" [13, 14], "as a rule at 670–630 °C" [13]. We suppose that transformation at ~650 °C can provide extremely quick diffusion at 670–630 °C and to explain several tendencies:

• so-called "wonderful fact" [13];

• "essential rise of steel ductility and toughness" during short-term annealing (tempering) at 650 °C [15];

• elimination of "increased hardness, wear resistance and ability to deformation strengthening" in the steels U10 (У10) and U15 (У15) with different carbon content during five-minute heating up to 650 °C [16];

• absence of traces of antimony atoms (that are large fractures with liquidated backward brittleness in comparison with ferrum of antimony atoms in Auger spectra), though the "time required for elimination of segregations is very small" [17];

• absence of "dispersed particles of vanadium carbide" in pearlite that has been "formed at 630 °C during 30 s in "hypoeutectoid steel containing ~3% of vanadium [18].

G. Lozinsky in his monograph [19] presents the curve of "hot" hardness of carbonyl ferrum in the temperature interval 20–750 °C. In the interval 550–650 °C hardness decreases by 20 kg/mm², while in the interval 650–750 °C — by 7 kg/mm². This approximately three-fold lowering of the rate of hardness decrease above 650 °C means bend of the curve at 650 °C , what can be considered as a transformation attribute [6] at this temperature.

Results of investigations and their discussion

The effect of tempering temperature on upsetting resistance (P) for ferrum samples (containing 0.008% C) in the temperature range 540–740 °C is presented on the **fig. 1**.

At the temperature ~650 °C we can observe lowering of the rate of deformation force (see fig. 1), and it is described by repeat of the hardness curve of M. G. Lozinsky. Hardness in the temperature range near polymorphic transformation varies qualitatively in zirconium and titanium [19], cobalt, lanthanum and cerium [3]. It allows on the analogy to suggest also transformation in ferrum at the temperature ~650 °C.

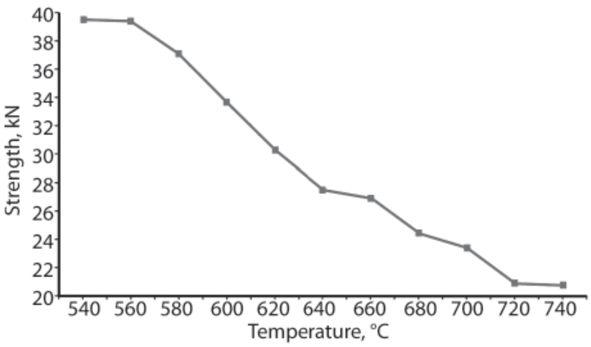

Fig. 1. Dependence of strength during half-height deformation of ferrum samples on temperature in the range 540–740 °C

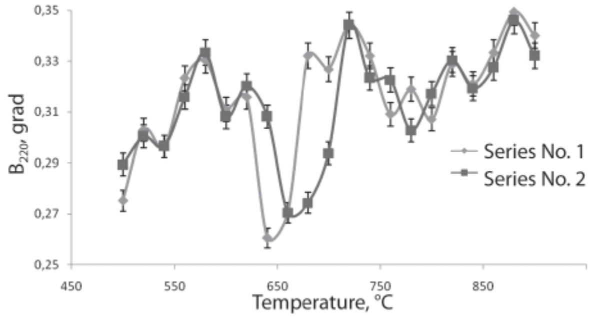

Fig. 3. Dependence of widening of diffraction maximal values of the line *220* (B_{220}) (averaged by three points) on tempering temperature of pure ferrum. Experimental series No. 1 and No. 2

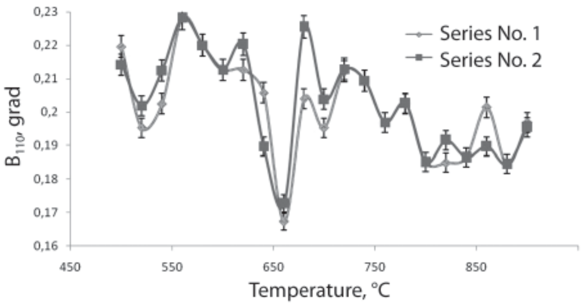

Fig. 2. Dependence of widening of diffraction maximal values of the line *110* (B_{110}) (averaged by three points) on tempering temperature of pure ferrum. Experimental series No. 1 and No. 2

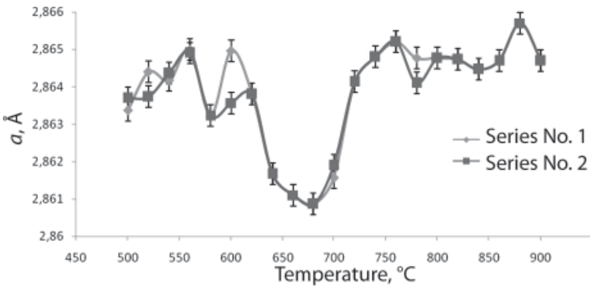

Fig. 4. Dependence of the lattice parameter (*a*) (averaged by three points) on tempering temperature of pure ferrum. Experimental series No. 1 and No. 2

Examination of parameters of ferrum fine structure (containing 0.008% C) were conducted on the samples that have been previously quenched in water from 1050 °C. Each tempering conditions (with 20 °C pace) were used for processing of three samples, and examination has been conducted two times on the same samples. The width of X-ray lines *110* (B_{110}) (**fig. 2**), *220* (B_{220}) (**fig. 3**) and lattice parameter (*a*) (**fig. 4**) have been determined according to the standard techniques. The measuring error in the first and second experimental series does not exceed 1.5%.

The minimal values of width of the lines *(110)* and *(220)*, as well as the lattice parameter (*a*) at the temperature ~650 °C are displayed on the fig. 2, 3 and 4. It can testify on variation of the ferrum fine structure at ~650 °C. It should be emphasized that the minimal values are not revealed if the experiment is conducted with the pace 40–50 °C. Respectively, variations of the fine structure occur in very narrow temperature interval.

Conduction of metallographic investigation after heating of ferrum polished sections (containing 0.008% C) up to 850 °C and isothermal holding from 580 to 680 °C with the pace 20 °C has displayed that pickling ability is harshly contrast after holding at 640 °C (**fig. 5, *b***); other close to 640 °C kinds of microstructure at the temperature 620 °C (**fig. 5, *a***) and 660 °C (**fig. 5, *c***) are presented.

Contrast pickling ability, as well as emission of electrons, is an attribute of crystallographic perfection of separate grains that cross the plane of polished sections under different angles to crystallographic planes. This "perfection" can be connected with transformation in ferrum.

Three singular points (minimal values) at the temperatures ~450 and 900 °C [3, 20] are presented on the temperature relationship of ferrum toughness. The first point can be connected with proposed transformation in ferrum [21], while the second point — with unconditional ferrum polymorphism. The third point marks maximal value at ~650 °C [3] and (by P. Oberhoffer) at ~625 °C [12].

The yield strength of monocrystal of high-pure ferrum has a maximal value — an attribute of transformation at ~600 °C in the temperature interval 300–900 °C (with testings conducted with 100 °C pace) [22]. To hide this maximal value, the curve has been built without crossing the experimental value at 600 °C, the only point from 34 points presented on the figure. E/ M. Savitsky has also built the curves δ and ψ without crossing the experimental points at 600 °C, and that made the extremal points as attributes of transformation at these curves and testing temperature less expressive [3].

Distinct bends are observed on the temperature relationships $\sigma_{0,2}$ and σ_B at the temperature ~650 °C (in the same way as at ~450°C) for steel AK29 (low-carbon medium-alloyed steel, composition is not mentioned). The curves obtained at extension rates 0,4 and 2×10^{-3} s^{-1} [23] are crossing at ~650 °C, what means elimination of influence of rate as the second factor, while extension temperature is the first one. The authors believe that these results are possible in the case of transformation at ~650 °C. This transformation can be a

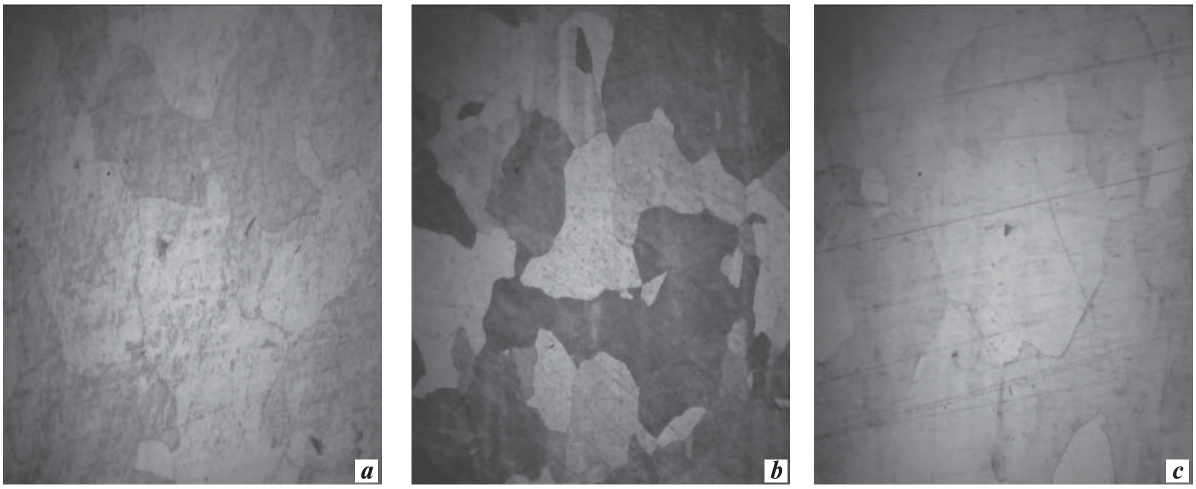

Fig. 5. Pure ferrum microstructure after heating up to 850 °C and isothermal holding at 620 °C (*a*), 640 °C (*b*), 660 °C (*c*), ×200

dominating factor neutralizing the difference in mechanical behaviour at the above-mentioned extension rates.

Conclusion

The anomalies on temperature relationships of mechanical and physical alloys can be caused by transformations in ferrum at ~650 °C, what can probably determine the anomalies of mechanical behaviour of steels. Recognition of transformation at ~650 °C allows to explain the following parameters: extremal properties of products of austenite isothermal transformation, interrupted quenching, martensite tempering; excessive diffusion; appearance of motivation to austenite rercrystallization; speculative nature of inversed tempering brittleness etc.

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