channel. Thereby, high intensity of gas circulation in the ladle is provided irrespective of the thermal output. This enables creation of the optimal gas-dynamic field within the ladle and helps to design efficient drying schemes at all the process stages.

This technology has been implemented and verified in operation at different installations: vertical and horizontal, designed for steel ladles varying in capacity from 30 to 350 tons as well as for intermediate ladles of continuous-casting plants and hot-metal ladles (Fig. 2).

Conclusions

A method was developed for numerical simulation of the drying process as applied to lining materials for metallurgical ladles. This method enables designing of optimal control of the process in order to enhance the quality and durability of lining and to minimize energy and time consumption;

Introduction of this optimal drying technology allows to save 20–50 % of fuel and accelerate the drying process by several times as compared to conventional drying methods;

The main advantage of the optimal drying technology is enhancement of the lining durability up to the manufacturer-specified levels due to elimination of internal damage to the material.

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Criterion estimation of severe plastic deformation efficiency from the position of their influence on the carbon steel structures evolution

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Currently there is practice of application ultra-fine grain (UFG) materials, including steel, in low-sized details (fittings, medical instruments, implants), low bulk commodities in research labs. But yet there are no manufacturing technologies for production of such materials which will allow to obtain a blank and to scale it up to the dimensions of half-finished product (sheet, rod). Besides, usage of steel with UFG structure is limited by poor knowledge of their mechanical and performance attributes.

We can't develop manufacturing process of producing hardware items of steel with UFG structure without solving problem of definition the structure and properties evolution in the course of deformation process. However, a very important part in the development of manufacturing process for shaping different material types including constructional steel with UFG structure is the limits of deformation ratio definition for concerned real process of producing finished product. These limits can be found in the course of research investigation about changes in the structure of work material after achievement it's yield value.

The results of metallographic examination show the change in interlamellar distance in pearlite structure of low and medium carbon steel grade C22E and C45E after equal channel angular extrusion (ECAE). Statistical analysis of the experimental data indicated that interlamellar distance in pearlite structure of steel grade C22E is 1.5–2-fold smaller then in steel grade C45E (Fig. 1). The interlamellar distance in pearlite structure of steel grade C22E changes from 0.27 to 0.18 micron and in the steel grade C45E from 0.58 to 0.24 micron after increasing the number of passes in the ECAE. The flakes of cementite at the expense of severe deformation in the pearlite structure are bending (Fig. 2 a), fractionizing (Fig. 2 b) and there is subsolution with the development of the supersaturated ferrite area (Fig. 2 c)

When increasing the number of passes in the ECAE process, we can observe the development of the ferrite frag-

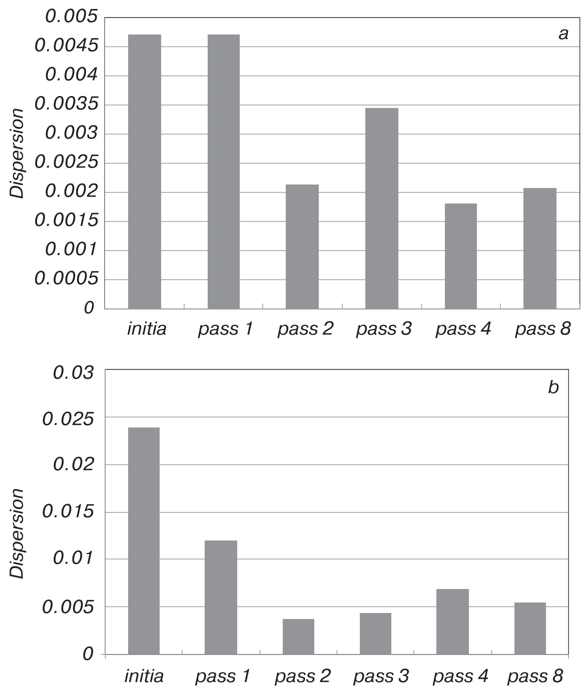
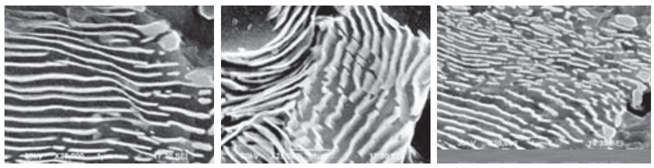


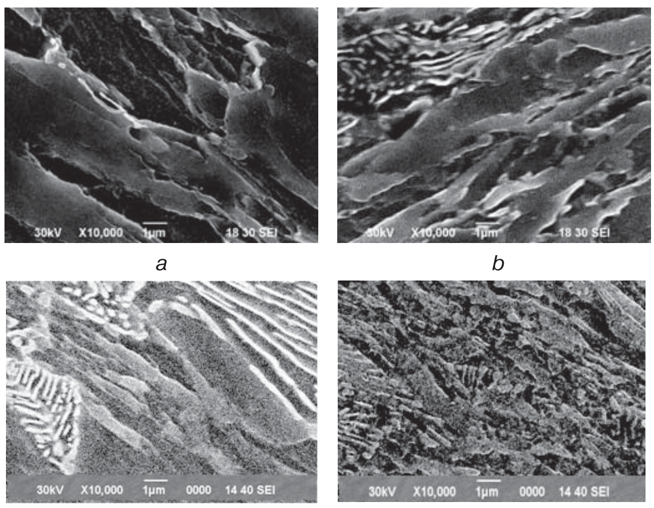
Fig.1. Dispersion variations of the interlamellar distance in pearlite structure of steel grade C22E (a) and C45E(b) depending on the number of passes in ECAE



a *b* *c*

Fig.2. Deformation of cementite plates in the ECAE process

mentation in the steel grade C22E and C45E. Volume fraction of fragmented ferrite increases from 5–7 to 70–80 %. It is established that after the first pass of the observable steel grades in the ECAE process there is development of deformational stripes (fibers) consisted in ferrite grains (sub-grains) which are extended in one direction (Fig. 3). In addition, the mean value of the deformational stripes width belongs to the interval with the meaning 0.3–0.8 micron (Fig. 4). Besides, after second pass (especially for steel grade C45E) this parameter considerably goes down and then changes insignificantly. Analysis of variance showed that degree of this parameter dispersion from pass to pass continuously goes down both for steel grades C22E and C45E (Fig. 5).



a *b* *c* *d*

Fig.3. The change of fiber width in ECAE process after 1 (*a*, *c*) and 8 (*b*, *d*) passes for steel grades C22E (*a*, *b*) and C45E (*c*, *d*)

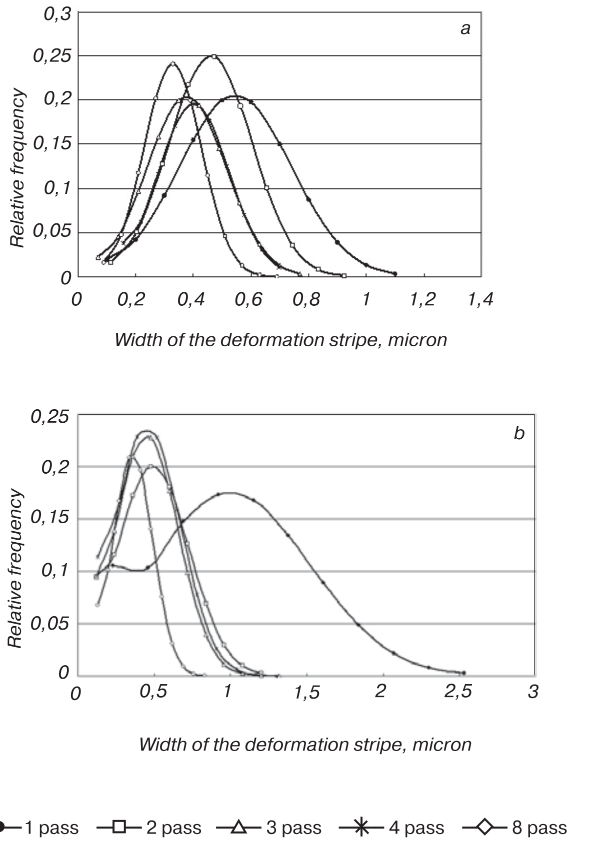


Fig.4. Frequency curve of the density distribution of the deformational stripes width by passes in ECAE process for steel grades C22E (*a*) and C45E (*b*)

There are grains of practically equiaxial geometry with large-angle boundary forming inside the deformational stripes (fibers) under the deformation – so called "fragments". In addition, the size of ferrite fragments works out 0.7 micron after 1 pass and reduces in the ECAE process to 0.5 micron for low-carbon steel grade C22E. The size of ferrite fragments changes from 0.75 to 0.5 for medium-carbon steel grade C45E (Fig. 6). There is heterogeneity of the neither grain size for low-carbon steel grade C22E or medium-carbon steel grade C45E on the initial stage of ECAE process (1–3 passes). There is reduction of not only average dimensions of ferrite fragments but the size of grains by increase the number of passes (i.d. by increase the meaning of deformation ratio). It is confirmed by statistical analysis of findings (Fig. 7).

There were received estimation efficiency criteria of the deformation process nanopatterning for the quantitative ratings of the abilities of UFG steel for obtaining adequate mechanical characteristics for different types of severe plastic deformation. The efficiency of the deformation process nanopatterning means revision state of the structural steel

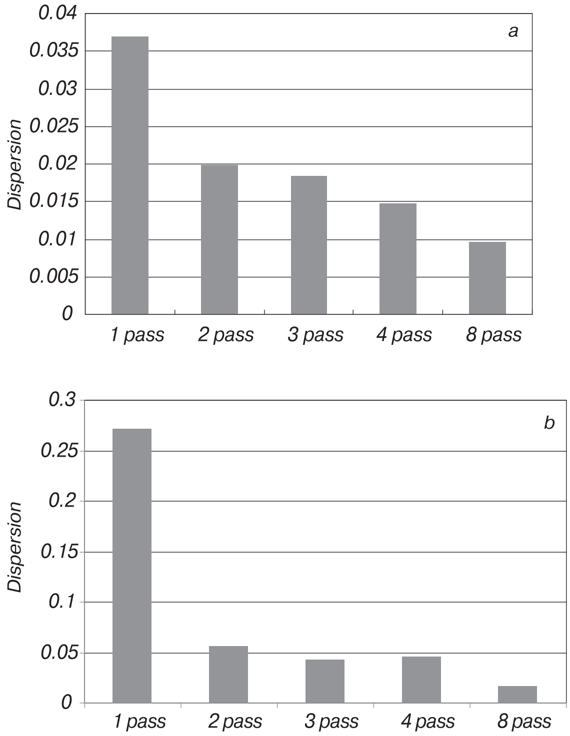


Fig. 5. Dependence of the deformational fibers width from the quantity of passes in ECAE process for steel grades C22E (a) and C45E (b)

mechanical characteristics under the deformation. On the assumption the main point of the formulating and solution of the end problem in the metal working we can mark out 2 criteria groups (Fig. 8). The first group defines initial ability of the wrought steel to receive impact with relation to the change of their mechanical characteristics, and the second group defines a variation of rearrangement for structural steel in the deformational processing. In addition, the second group defines the level of mechanical characteristics after manufacturing operations and inherently describes time history of steel structure peculiarities which lead to (or perhaps lead to) the change of strength and plastic properties.

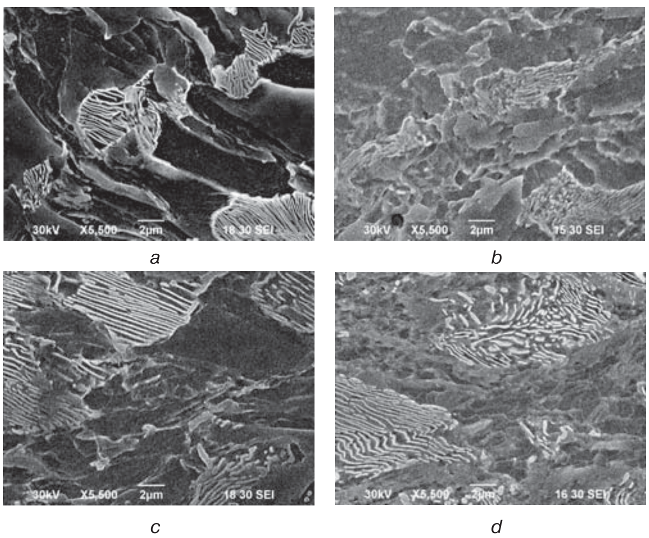


Fig. 6. Dimensional changes of ferrite fragments for steel grades C22E (*a*,*b*) and C45E(*b*,*c*) after one (*a*,*c*) and eight (*b*,*d*) passes in ECAE process

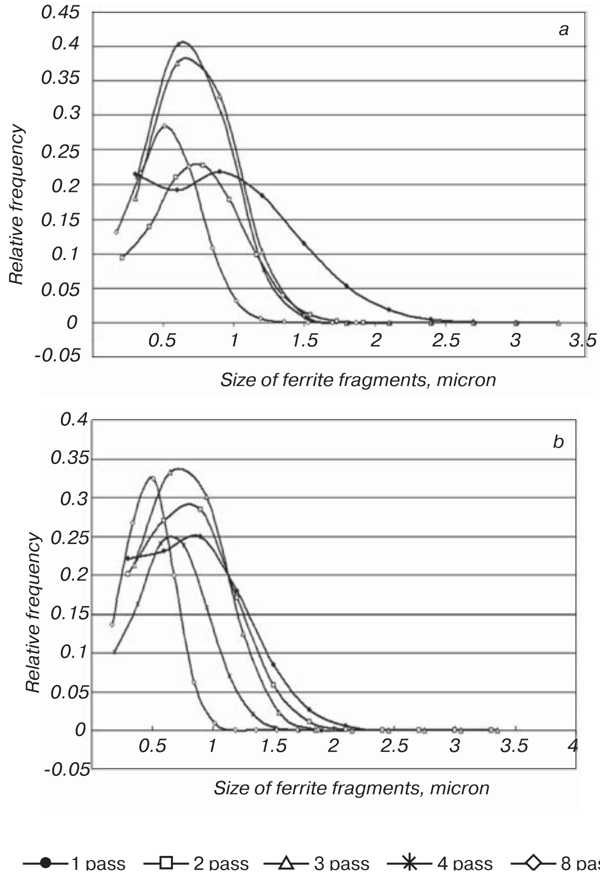


Fig. 7. Frequency curve for the density distribution of ferrite fragments size by passes in ECAE process for steel grades C22E (a) and C45E (b)

It has been suggested that criterion which is defined as dependency of the ferrite and cement carbide thickness in pearlite structure of structural steel will be used for quantitation of ferrite-carbide composition dispersivity. Increasing of the ferrite parts constituent in thin-platy pearlite structure definitely brings to the increase of nanopatterning efficiency (with relation to the mechanical characteristics changes in question of deformation process), that's why K_1^o should be bent on max ($K_1^o \to \max$).

The second criterion which defines initial ability of the wrought steel to receive impact with relation to the change of its mechanical characteristics is part of ferrite constituent (K_2^o). Increase of the ferrite part constituent in structural steel definitely brings to efficiency upgrading of nanopatterning process which causes the maximization of this mechanical characteristics variation quantity necessity. That's why condition of efficiency is $K_2^o \to \max$.

Conducted in Magnitogorsk State Technical University analysis of carbon steels showed that there is intensive dispersion of structure elements which causes increasing of strength and hardness in 1.5–1.8 times in ECAE process. First pass provides growth of major strength properties on 60-65%, and last pass just on 10–17 %. Plastic characteristics also considerably go down only after first pass-approximately on 30-40% and after next passes they change a little.

According to this we can separate out 3 criterions defining time history of steel structural features which reduce (or maybe reduced) to changes of strength and plastic characteristics.

The change of fragmented ferrite gaining volume fraction in the course of severe plastic deformation (SPD), for example in ECAE process, formalizes as sum (accumulation) of each deformational operation of change (notably reduction) part of no fragmented ferrite modified to the initial ferrite volume fraction in the composition of structural steel. Decrease the part of no fragmented ferrite after each pass as follows from experimental data reduces efficiency of deformational process that's why this criterion should be bent on min ($K_1^{\partial} \rightarrow$min). The second dynamic criterion (K_2^{∂}) is variation of interlamellar distance in pearlite structure. Similarly to criterion K_1^{∂} physical meaning of this efficiency criterion for nanopatterning is the sum (accumulation) of each deformational operation for change (notably reduction) of interlamellar distance in pearlite structure modified to the initial interlamellar distance in the composition of structural steel. It should be noted that formalization transcript of this criterion won't change if we consider spheroidized cementite. In this case $l_{\phi o}$ and $l_{\phi i}$ values will indicate the distance between neighbors spheroidized carbides.

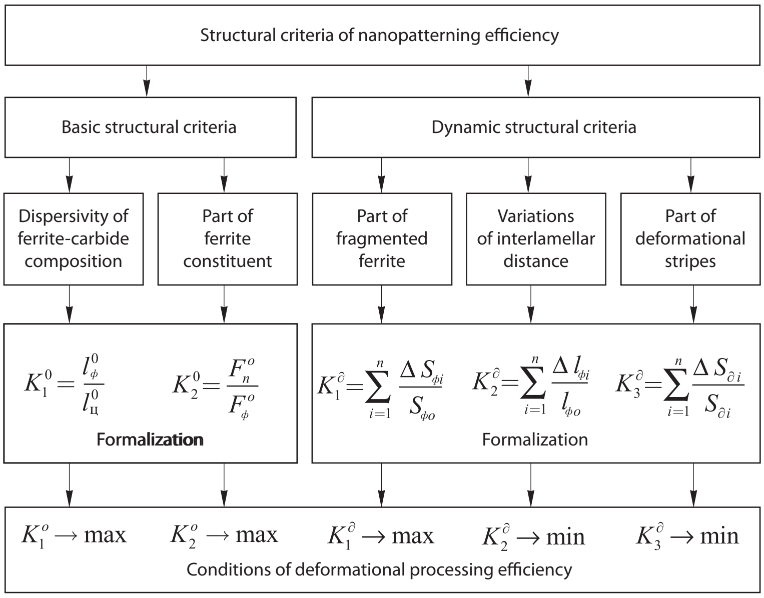


Fig. 8. Criterion score scheme of deformational processing efficiency for structural steel

Decreasing of the interlamellar distance in pearlite structure by passes in deformational process as follows from experimental data reduces efficiency of deformational operation, that's this criterion should be bent on min ($K_2^{\partial} \rightarrow$ min). Third dynamic criterion (K_3^{∂}) is the change of deformational stripes volume fraction in the composition of structural steels after SPD. For the determination of this criterion we will use developed principle of nanopatterning process efficiency evaluation. This criterion we can find as a sum (accumulation) of each deformational operation for change (notably increase) volume fraction of deformational stripes modified to the last meaning of deformational stripes volume fraction in composition of structural steel. In this case the absolute increasing of volume fraction in deformational stripes of ferrite $\Delta S_{\partial i}$ by passes in deformational process can be written as $\Delta S_{\partial i} = S_{\partial i} - S_{\partial o}$ where $S_{\partial i}$ and $\Delta S_{\partial i}$ - properly the areas (volume fractions) of ferrite without deformational stripes (initial condition) and ferrite with deformational stripes after deformational operation in composition of structural steel. Efficiency of deformational impact for current criterion can be written as $K_3^{\partial} \rightarrow$ min.

Thereby, criterion estimation of nanopatterning efficiency is a base for the engineering new schemes for severe plastic deformation of carbon structural steels. Obtained results will determine graininess and degrees of deformational impact when constructing manufacturing technologies of producing metalware with UFG structure, forming efficient conditions for the guaranteed achievement of required qualities of final product.

Features of shaped cold-bended sections of production of heavy-duty steels

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Requirements toughening in contemporary dynamic market results in necessity of new engineering solutions search and instantaneous adaptation of the existing technological resources of an enterprise to highly remunerative metal production manufacturing. It is especially urgent for producers relating to deep metal treatment including producing of shaped cold-bended sections (CBS).

Today Magnitogorsk Metallurgical Integrated Works (MMIW) is one of the first-rates producers of CBS in Russia, which produces more than 700 cold-bended section types of different steel grades from low-carbon to alloyed ones. Meanwhile it is the single Russian producer of particular section types for needs of railway carriage repair and rail carriage building works for example.

The significant part of bended sections manufactured at MMIW consists of shaped cold-bended sections being produced by profile-bending machine (PBM) 2-8×100-600 of "traditional" grades range (09G2(S,D), 10KhNDP, St3sp, ps). The feature of forming by PBM 2-8 is the single-piece profiling of hot-rolled strip semi-finished section lengths,