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 ($K_2^{\partial}$) is variation of interlamellar distance in pearlite structure. Similarly to criterion $K_1^{\partial}$ 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.

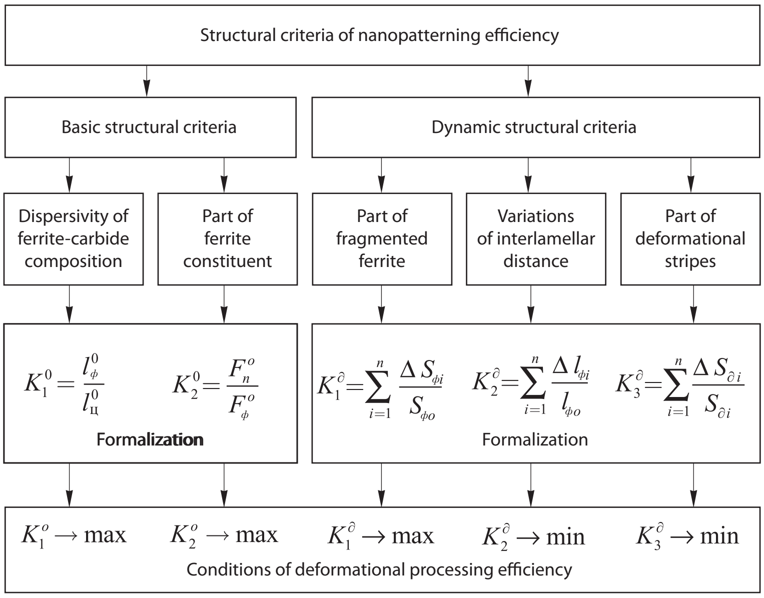


**Fig. 8. Criterion score scheme of deformational processing efficiency for structural steel**

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 ($K_3^{\partial}$) 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, which results in unavoidable dimensions deviation in the ends areas and appearance of flanges defects (Fig.1).

This is connected with influencing of so-called «rigid ends» and appearance of nonuniform elastic stresses in different section elements. By the aforesaid reasons cross-section dimensions, twisting and curvature control in all of standards is regulated at a defined distance from the ends of bars. For example standards for steel bended equal flange sections (the State Standard GOST 8278-83), steel bended non-equal flange sections (the State Standard GOST 19772-93) and steel bended non-equal flange angles (the State Standard GOST 8281-80) regulate following control distances from the ends (table 1).

But today consumers make tougher their requirements to bended sections' quality, which is induced besides over by reducing of discharge coefficient for processing and using of metal products. Thus for example, during assembly of truck frames of longeron workpieces by customers (PC «KAMAZ», PC «MAZ», PC «UralAZ») they are dissatisfied by significant dimensions' deviation on rather large distance from the ends (see table 1). In addition, the greater strength properties of profiled metal are, the greater the deviations are and the greater the dictation is. Thus on the one hand we can mark the goal of profiling technology development which permits to minimize the end defects formation. On the over hand it is necessary to conduct a test complex for analyses of steel grade (it's chemical composition) influencing on finished sections' properties forming.

**Table 1. The regulated distances for dimension measurements of bended sections after single-piece profiling**

| Standard | Distance from the section end, mm, when profile accuracy is | | |
|---|---|---|---|
| | high | elevated | regular |
| State Standard GOST 8278-83 | 80 | 100 | 200 |
| State Standard GOST 8281-80 | 150 | 200 | 300 |
| State Standard GOST 19772-93 | 100 | 150 | 300 |
| Specification 14-101-406-98 | 500 | | |

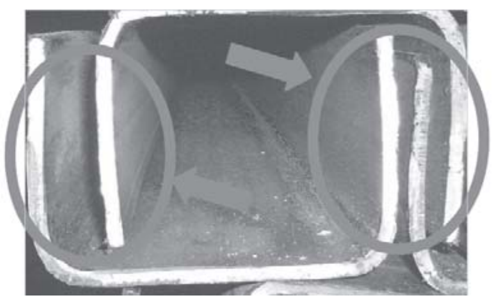

**Fig. 1. Bended sections' defects forming during single-piece profiling**

Specialists of Magnitogorsk Metallurgical Integrated Works together with scientists of Magnitogorsk State Technical University conducted a test complex to define influencing character of the main technological factors of profiling process (quantity of forming mills, unit angles of overcast, mechanical properties of incoming etc.) on obtained dimensions and form quality level. The tests were conducted in the network of technology development for producing bended sections of special dimensions 150×180×300×8 mm. The finished bended section's appearance is presented on the Fig. 2.

This bended section is used for strengthening of bridge constructions, i.e. requirements for dimensions and mechanical properties are rather severe. For example, tolerance for main dimensions (difference in flanges heights, difference in bases wides) in a distance of 12 m is limited by value ±3 mm. Before such sections were not produced in Russia and were imported.

Development of BS 150x180x300x8 producing technology was realized in several stages. First of all the profiling technology studying was realized on rolled metal of S420MC steel grade in accordance with DIN EN 10149-2:1995 requirements. This steel has elevated strength properties (table 2).

For this section producing the new technology was designed; it included strip forming in seven mills with corresponding particular overcast angles ($10^{o}$-$20^{o}$-$32^{o}$-$45^{o}$-$65^{o}$-$67^{o}$15'). The calibrating calculation was based on traditional methods without taking into account features of steel chemical composition, which is microalloyed by carbonitride forming elements. As the result of the first test milling of rather strength steel, the main dimensions deviation level in the range of ±5 ÷7 mm was obtained, which was unallowable for a consumer. During the analysis of the first test results it was decided to increase passes quantity to 8 and to change particular overcast angles in the finishing mill correspondingly ($10^{o}$-$20^{o}$-$32^{o}$-$45^{o}$-$58^{o}$-$65^{o}$-$67^{o}$30'). After that the required level of dimensions was obtained (fig. 3).

The consumer wished to produce this section type of "traditional" steel grades (10KhSND, 09G2S and their analogies) at following stage of development. During producing of BS 150×180×300×8 of low-alloyed steel grades using

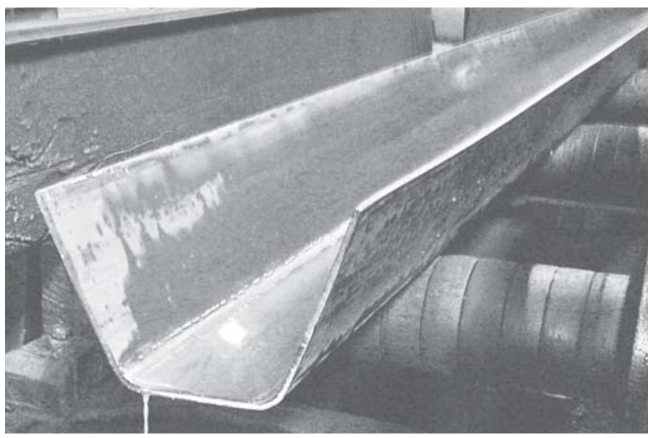

**Fig. 2. Appearance of bended section of 150×180×300×8 mm**

| Table 2. The mechanical properties of hot-rolled steel of S420MC (h=8mm) | | | |
|---|---|---|---|
| Parameter | Mechanical properties | | |
| | Yield point, $\sigma_{T}$, N/mm$^2$ | Tensile strength, $\sigma_{B}$, N/mm$^2$ | Percent elongation, $\delta_5$, % |
| Actual value | 480–510 | 530–650 | 26–31 |
| Required value EN10149-2:1995 | ≥19 | 480–650 | ≥19 |
| * - Averaged values | | | |

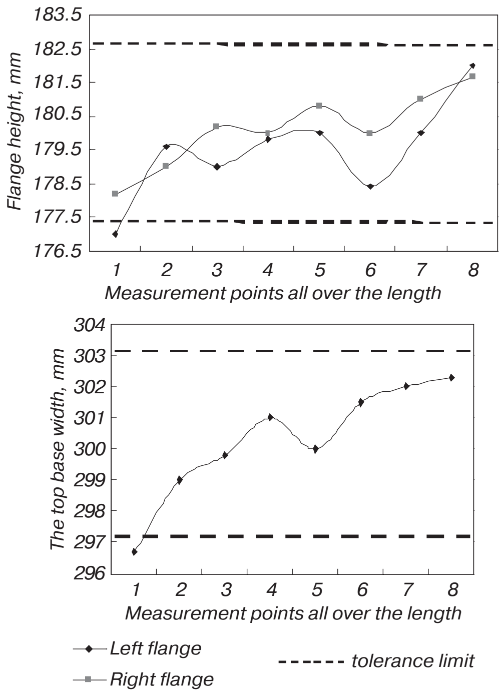


**Fig. 3. The obtained dimensions for BS 150×180×300×8 of steel grade S420MC**

calibration designed for S420MC steel grade the problem of dimensions and form stability along the product ensuring appeared. This situation demanded additional tests conducting for analysis of mechanical properties of hot-rolled metal (mechanical properties are changing during profiling). It was determinated that low-alloyed steels has elevated (in comparison with S420MC steel) springing, which in conditions of single-piece profiling without back tension leads to significant twisting in ends areas that increase dimensions unstability. Therefore it was decided to switch over to increased passes quantity when forming of profile of this steels class. The following private overcast angles were adjusted: $10^o$-$20^o$-$32^o$-$45^o$-$53^o$-$60^o$-$65^o$-$67^o30'$. Forming scheme changing allowed providing the required quality level of cold-bended sections in the field of dimensions and form. During studying adaptation model was suggested for quality factors of bended sections which included taking into account rheological properties changing of forming material.

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