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Research of the Influence of Deformation Speed on Energy and Power Adjectives of the Process of Three-point Cold Bend Breaking and on Alignment Integrity of Raw Parts

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Data on the amount of general energy of deformation and destruction, and also on its constituents, duration of different phases of destruction, speed of the main shock-induced cracking for materials with different mechanical properties in three-point cold bend breaking with the use of multichannel system of high-speed registration of loading is obtained. On the basis of the analysis of experimental data conclusions are drawn about the influence of loading speed on energy and power adjectives of partitioning and about alignment integrity of raw parts of different steel grades.

Keywords: BEND BREAKING, BLOW, VELOCITY, ENERGY, QUALITY, PROPERTIES OF MATERIALS

1. Introduction

An important direction of machine-building production perfection is the development of the ways of reduction of metal consumption in production of raw parts and also the increase of accuracy and productivity of rolled metal cutting, as the indicated factors substantially influence technical and economical indexes of subsequent manufacturing processes.

Among well-known waste-free methods of high quality rolled metal cutting the special place is occupied by cold breaking, the basis of which is the guided destruction of rolled metal notched at bend. The method of cold bend breaking is characterized by low power consumption, simplicity of realization, possibility of partition of hard and high-strength materials without heating. However to use bend breaking advantages to a full extent is possible only under conditions of taking additional measures for breakthrough improvement of chip quality and reduction of power consumption of destruction process, because the tense resilient state is created in the area of rolled metal a few diameters long and only a small part of resilient energy goes to the creation of the crack. The rest of resilient energy is expended to the plastic strain in macro volume – in the area of contact with striking body and supports [1].

In addition, as a result of the analysis of regularity of rolled metal forming and destruction it is exposed that the development of geometrical defects during breaking is also caused by plastic flow in the process of partition.

2. Statement of problem

One of promising techniques of reduction of the level of plastic strain is the use of high-speed loading. Of great importance is the study of the issues of deformation speed influence on strength properties of metals by the following scientists: Ioffe A.F., Davidenkov N.N., Shevandin E.M., Hopkinson D., Erdogan E., Ekobori T., Pearson D., Sokolov L.D., Polukhin P.I., Goon G.Ya., Galkin A.M., Parton V.Z. and others [2]. Development of new high-speed processes of partition of high quality rolled metal into cut-to-length sections must be based on the up-to-date methods of experimental analysis. Knowledge of material behavior during an impact is one of the necessary requirements of correct choice of processing methods of partition.

However determination of the blow effort amount because of very short duration of impact represents a definite problem. Short-time loading action and arrival of wave effect with the increase of deformation speed considerably complicates the analysis of materials behavior and the influence of loading speed on its mechanical properties.

Numerous experimental data prove the loading speed susceptibility of materials, i.e. the loading speed can both increase and diminish the strength properties depending on the structure, composition and technology of their obtaining. However announced experimental data is contradictory in itself and its volume is insufficient, especially as it applies to the processes of partition of high quality rolled metal into cut-to-length sections.

With the purpose of obtaining such information experimental researches have been conducted on the three-point cold bend breaking of samples of different grades of steel under static and shock loadings.

3. Experimental procedure

Traditionally shock tests are conducted with the use of impact testing machines, which determine the energy, expended for destruction of samples [3] and the quantity of binding constituent in a fracture or the value of transversal expansion of a sample in the fracture area by the fracture appearance. More full-featured possibilities for the similar tests are provided by the use of hammer presses with hydro elastic drive developed at the Donbass State Engineering Academy (Kramatorsk, Ukraine). A hammer press has the followings basic advantages: the possibility of creation of quasi-static, impact and combined loadings in a wide range of speeds, energies and forces; exact dosage of energy or force during deformation of raw parts etc. [4].

For the experiments a hammer press was used with the following features: peak blow energy is 1.3 kJ; developed force is 106 kN; the highest theoretical speed of moving parts is 24.6 mps and appropriate to it shaft motion is 114.6 mm; accumulator volume is $12\cdot10^{-3}$ m^3; maximal working pressure is 18 MPa; the weight of moving parts is 6.25 kg.

Figure 1 shows the registration pattern of the experimental data (**Figure 1a**), structural chart (**Figure 1c**), photograph of the experimental equipment (**Figure 1b**) and the rigging (**Figure 1d**).

Equipment for the partition of samples by cold breaking method (**Figure 1c**) consists of: bed 1, in the guide ways of which clamping mechanisms for the rolled metal, a breaking element and supports are installed and adjusted with recurrent-forward motion ability, limited by the supports 2 and by protective straps 3, which are fastened to the bed 1 by bolts. Position of clamping mechanisms, breaking mechanism and supports is fixed by bolts 5, screwed into supports 2, nuts 4 and space plates 6. The mechanism for rolled metal clamping consists of casing 7, the port of which accommodates sample 15 between half-sleeves 8, which are stopped by bolt 9, screwed into casing 7. The breaking mechanism consists of casing 10, breaking element 11 adjusted with guide ways for recurrent-forward motion. The mechanism of support consists of casing 12 and supporting plate 13, which is held by a protective strap 14 screwed by bolts with rings.

In the capacity of strain sensors for breaking mechanism loading and rigging supports registration resistive-strain sensors ФКТК 10-200 С-I were used, enabled in half-bridge circuit. Data from strain sensors was fed to PC through the universal multichannel data collection and recording device E-440, where, after certain treatment by original software, it was kept in tabular and graphic view comfortable for subsequent analysis.

Key features of the recording device E-440 are specified below: recent digital signaling processor ADSP – 2185M with 48 MHz clock rate; 16 differential channels or 32 channels with common earth for analog input with the possibility of automatic adjustment of the initial point; maximal frequency of work of the 14-bit ADC is 400 MHz, which allows to use this device for the research of shock processes.

Due to availability of several paths of registration signals were streaming simultaneously through 3 paths: breaking mechanism 1 and supports 4 (see **Figure 1**). The experiment employed cylindrical samples of rolled metal of different steel grades of 16 mm in diameter and 150 mm long, being in plastic (Ст.3), elastoplastic (Сталь 20, 45, 40X) and fragile states (Сталь 60С2, ШХ15). Stress raisers in the form of annular grooves of triangular profile with the following parameters were preliminarily applied onto the samples with the use of a lathe tool: depth – 1 and 3 mm, radius at the top – 0,15 mm. The load application lever – 50 mm.

The dimensions of deformation areas and samples' destruction were determined by the analysis of surface fracture with the use of microscope.

Determination of geometrics characterizing geometrical accuracy of the samples was conducted using the method of macrostructure analysis measuring absolute and relative values of geometric distortions with the use of universal testing tool.

4. Experimental results

Model charts of time dependent energy and power parameters of the three-point cold bend breaking process of the partition of samples of different grades of steel with the concentrator of tensions Δh = 3 mm at static and shock loadings are presented in **Figure 2**.

The variation $F(t)$ at the three-point cold bend breaking of samples with the concentrator of tensions Δh = 1 mm at static and shock loading is presented in **Figure 3-4**.

The analysis of the obtained results of the experiments is presented in **Table 1**.

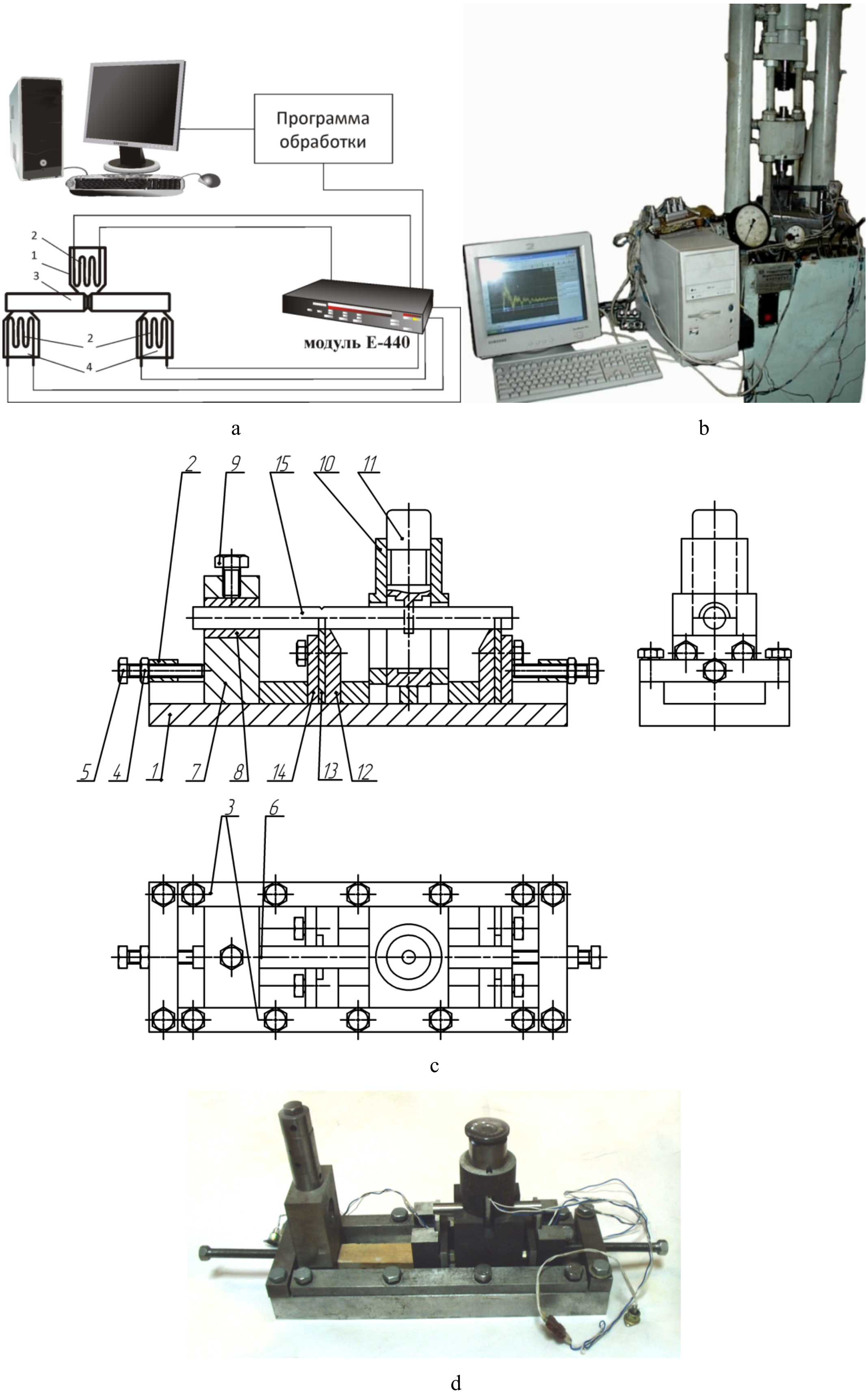
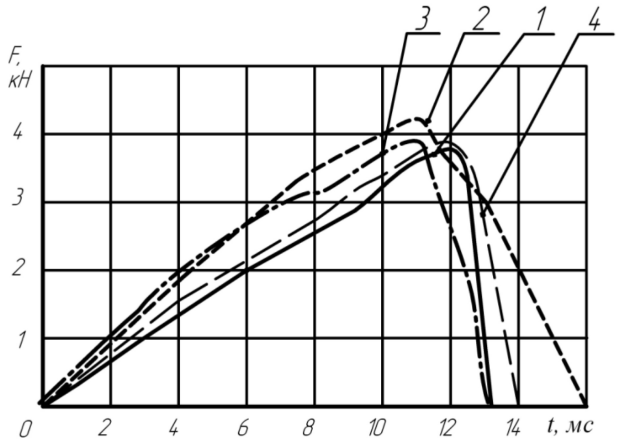


Figure 1. Pattern of experimental data collection (*a*), structural chart (*c*), photographs of the experimental equipment (*b*) and rigging (*d*): 1 – breaking mechanism; 2 – strain sensors; 3 – sample ; 4 – supports



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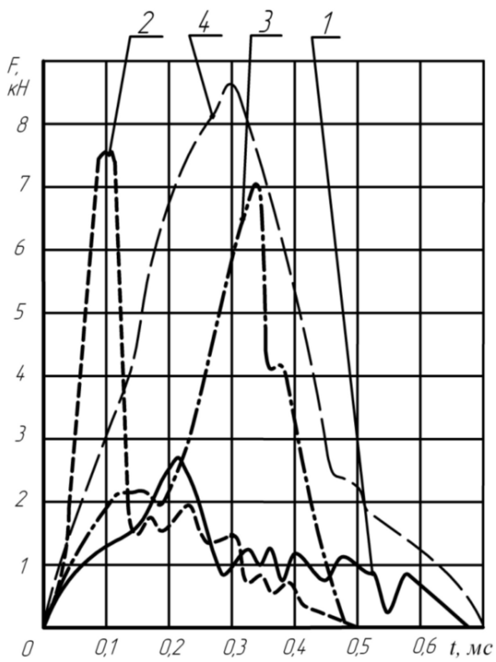


b

Figure 2. Dependence of breaking mechanism force on the time for the samples of different steel grades at Δh = 3 mm: 1 – Сталь ШХ15; 2 – Сталь 20; 3 – Сталь 40Х; 4 – Сталь 45; *a* – static loading; *b* – shock loading

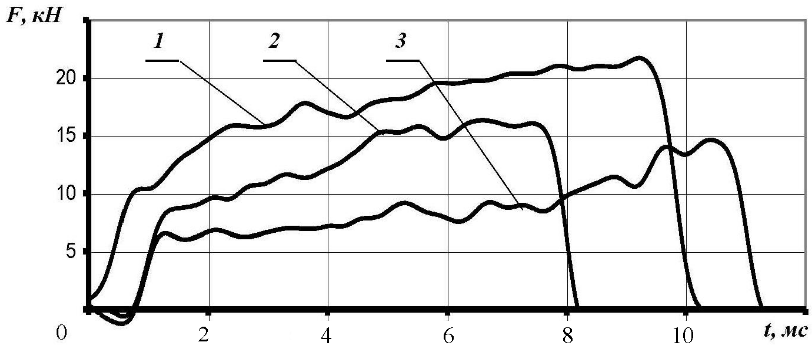
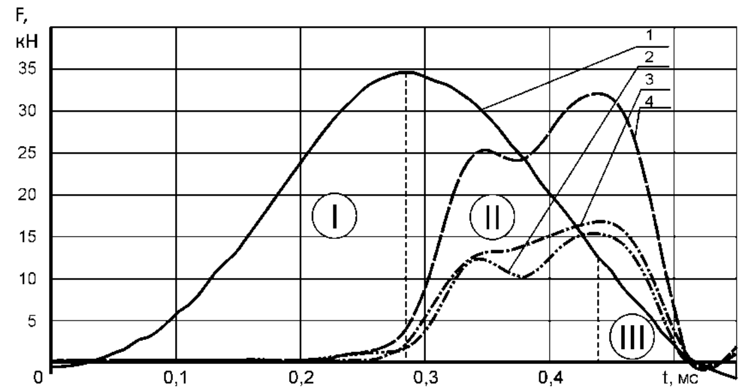


Figure 3. Dependence of breaking mechanism static force on the time for different steel grades at Δh = 1 mm: 1 – Сталь 60С2; 2 – Сталь 45; 3 – Ст.3



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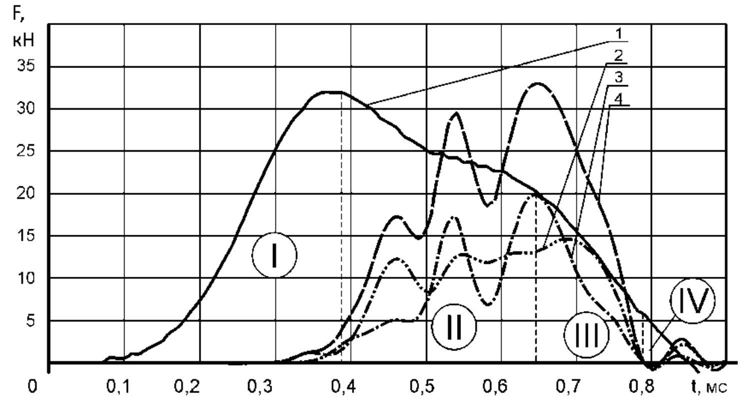

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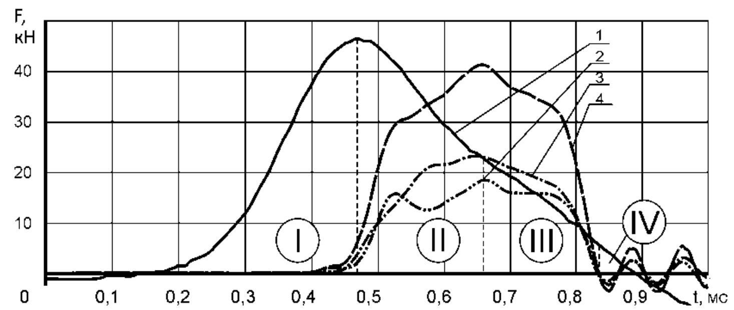

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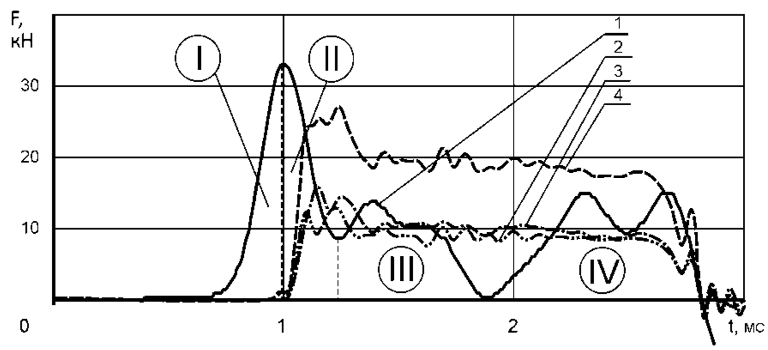


d

Figure 4. Charts of variation F(t) for different steel grades at shock loading (V=18 m/s) during the three-point cold bend breaking: *a* – Сталь 60С2; *b* – Сталь 45*; c* – Сталь *40Х; d* – Сталь 20; I – crack origination energy; II – energy of ductile crack extension; III – energy of fragile destruction; IV – ductile break down energy 1 – breaking mechanism force; 2 – force of support 1; 3 – force of support 2; 3 – sum of forces on supports

Table 1. Experimental results

Grade of steel	Top breaking force F_b, kN				Dynamic magnification factor k_d
	Δh = 3 mm		Δh = 1 mm		
	statics	dynamics	statics	dynamics	
ШХ15	3.8	2.7	–	–	0.7
60С2	–	–	22.0	35.0	1.6
45	3.9	8.6	16.0	32.0	2.0...2.2
40Х	3.9	7.0	21.0	45.0	1.8...2.1
20	4.2	7.5	22.0	35.0	1.6...1.8

The analysis of experimental data allowed drawing the followings conclusions.

1. Comparison of top breaking force at static and shock loadings was estimated by the dynamic magnification factor $k_d = F_{bd}/F_{bs}$, which for different grades of steel made up accordingly: ШХ15 – 0.7; 60С2 – 1.6; 45 – 2.0...2.2; 40Х – 1.8...2.1; 20 – 1.6...1.8. These results conform with data cited in [5], where k_d with the increase of deformation velocity up to 100 mps for Armco iron is increased in 3.4 times; for steel 45 – in 2.8 times; for steel 3 – in 2.9 times; for high-strength steels, e.g. ШХ15 – $k_d < 1$, what is explained by the initial processes of destruction in metal and allows to consider structural factor to be a determining one at the initial range of high-speed tests of materials.

In the obtained diagrams $F(t)$ (**Figure 4a**, **4b**, **4c**, **4d**) for the samples of different steel grades possessing a high sufficient resolution by both coordinates it is possible to define energy with its constituents expended for sample destruction: energy before the moment of crack formation and energy of ductile and fragile distribution of crack. In addition, taking into account high response speed of the system and possibility of accumulation of great volume of data, it is possible to preferentially examine the obtained signal duration of a few milliseconds long of very narrow temporal ranges (order of microseconds and tenth of a microsecond), that allows to estimate speed of crack distribution.

The quantity of energy constituents was determined by transformation of the relation loading F – time t into the relation loading F – time S. The experimental results are presented in **Table 2**.

Photographs of samples of different grades of steel split by the three-point cold bend breaking at static and shock loading are presented in **Figure 5**.

Analysis of experimental data shows that greater part of energy is expended on the origination and ductile extension of a crack while the energy expended on fragile destruction is insignificant. Crack breakthrough, attributable to fragile destruction, is observed at room temperature at temperatures below 50°C, which coordinates with experimental data [3].

Duration of crack breakthrough in the indicated areas of deformation and destruction I-IV (**Figure 4**) is presented in **Table 3**.

Analysis of **Table 3** shows that duration of breakthrough of fragile crack for different grades of steel makes t = 0.07...0.60 ms. It enables to estimate average velocity of distribution of fragile crack with sufficient accuracy (crack length was determined by the fracture surface of broken samples (**Figure 5**) which for the samples of different grades of steel was accordingly: 60С2 – 120 m/s; 45 – 80 m/s; 40Х – 60 m/s; 20 – 50 m/s.

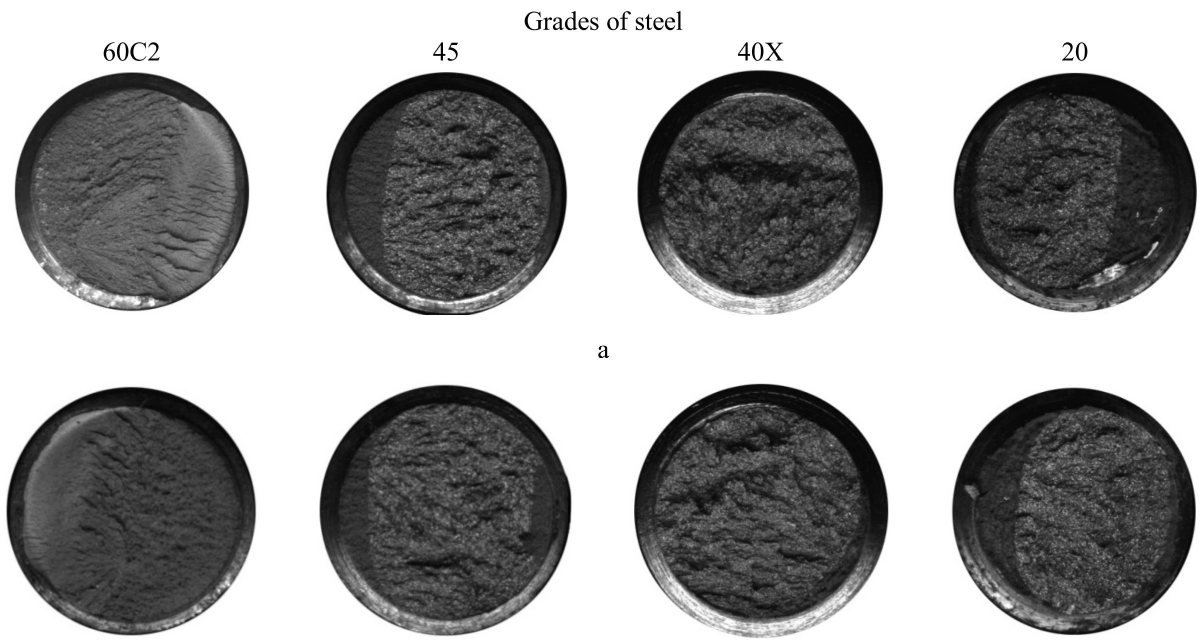
The analysis presented in **Figure 4** also shows evidently that load reduction takes place relatively smoothly at expansion of fragile crack, without sharp jumps. It is also possible to estimate the velocity of ductile destruction development – the cracking speed for the samples of different grades of steel is 10...25 m/s. Such values of speed coordinate with the estimation obtained in test results [3].

Analysis of geometrical accuracy of raw parts of different steel grades split by the cold bend breaking at static and shock loading (see **Figure 5**) allowed drawing a conclusion that with the increase of the deformation speed the quality of raw parts gets better but insignificantly.

The obtained results can be used for the perfection of the technology of partition process of high quality rolled metal into cut-to-length sections by the method of cold bend breaking.

Table 2. Quantity of overall energy of deformation and destruction and its constituents at speed V = 18 m/s

Steel grade	Overall energy of deformation and destruction, Joule	Energy of crack initiation, Joule	Energy of ductile crack extension, Joule	Energy of fragile destruction, Joule	Energy of fragile destruction, Joule
60C2	120.0	54.0	18.0	5.2	0.3
45	80.0	25.6	12.8	7.2	1.8
40X	90.0	35.1	12.5	6.7	1.7
20	110.0	20.9	4.0	5.5	8.8



a

b

Figure 5. Photographs of raw parts, obtained at static (*a*) and shock (*b*) loading by the method of three-point cold bend breaking

Table 3. Experimental results at V = 18 m/s

Grade of steel	Time of crack breakthrough in areas 1-4, ms (see **Figure 3**)			
	t_1	t_2	t_3	t_4
60C2	0.26	0.16	0.07	0.02
45	0.32	0.25	0.15	0.06
40X	0.34	0.18	0.17	0.06
20	0.60	0.30	0.60	0.95

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Исследование влияния скорости деформации на энергетические и мощностные характеристики процесса трехопорной холодной ломки изгибом и на сохранение геометрической точности заготовок

Карнаух С., Карнаух Д.

Получены данные о величине общей энергии деформации и разрушения, а также о ее составляющих, продолжительности различных фаз разрушения, скорости основного ударного разрушения для материалов с различными механическими свойствами при трехточечной холодной гибке с использованием многоканальной системы регистрации нагрузок. На основе анализа экспериментальных данных сделаны выводы о влиянии скорости приложения нагрузки на энергетические и мощностные характеристики разрушения и о сохранении геометрической точности заготовок из различных марок стали.