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Influence of a chevron type knife design on the quality of sheet material shearing

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Abstract
On the basis of laboratory researches of the separation process of sheet material by chevron type knives of the classical and modified forms with rounding off profile in top of a convergence of the inclined planes is considered. Using three various bar, as example, for each configuration of a knife the quantitative and quality assessment of shearing force is given and also a residual deflection of strips after shearing depending on rounding off radius. Higher efficiency of use of the modified knives is established. Results of work can be used for developing of the modified design of a chevron type knife and its implementation in industrial production.
Key words: THE CHEVRON TYPE KNIFE, THE SHEARING FORCE, A RESIDUAL DEFLECTION, THE SHEARING OF SHEET

A large part of rolled metal plate is used in industries such as oil and gas industry, ship-, bridge and machine building. And in modern conditions, the downward trend in this type of product of rolling production is not observed. At that, requirements for the finished sheet quality are of the high level.

Actually, the quality of finished rolled metal is formed at different stages in accordance with the technological scheme of plate production [1-5]. The cross cutting-to-length, which can be implemented on the shears of various designs, is one of the essential operations in such schemes.

The cross-cutting unit of NKMZ construction was successfully put in operation in conditions of OJSC “Magnitogorsk Iron and Steel Works”. The unit comprises lower

cut hydraulic shears designed for cross separation of sheet metal of 5 ... 25 mm in thickness and 1000 ... 2350 mm in width with the material tensile strength up to 1000 MPa.
This design of shears for cross strip separation uses the top chevron type knife [2, 3]. It allows providing of several advantages such as reduction of shearing force due to the slope of the knife edges by an angle 3º and uniform distribution of the load on the hydraulic cylinders due to the sheet centering by chevron type knife.

However, the practice of chevron type knife application showed the defect in the form of “tick” (or “house”), which is formed in the sheared part located under the chevron type knife (Fig. 1). In general, this defect does not exceed the flatness requirements of the finished hot-rolled sheet but spoils its market condition significantly and, in some cases, requires additional processing.

Today, there are several technical solutions [6-9] for this defect reduction. Technical solution [6], which was developed by the staff of OJSC "Severstal", implies the existence of a horizontal platform in the top of knife inclined planes convergence; length of this platform is proposed to be determined by the empirical formula. The knife stepped version with horizontal and inclined sections is assumed in the technical solution [7] proposed by PJSC "NKMZ". In papers [8, 9], the chevron type knife with a concave (classical) and curved (modified) arrangement of knife inclined planes with profile rounding off in the top of their convergence.

However, for evaluation of the effectiveness of these technical solutions, it is necessary to carry out the experimental researches which were the objective of this paper.

a b

Figure 1. View of the sheets end face sheared by chevron type knives: a - general view; b - in the linkage region of the chevron knife edges

Experimental researches were carried out under the cooperation agreement between the Donbass State Engineering Academy (Kramatorsk, Ukraine) and PJSC "NKMZ". The technical solutions [8, 9] were selected for experimental effectiveness evaluation, as in paper [10], higher solution effectiveness of [8] than [6] was shown, and technical solution [7] was excluded from consideration at the initiative of PJSC "NKMZ".

As an experimental installation, the laboratory press shears for rolled metal plate cross-cutting of "Mechanics and plastic molding" department of the Donbass State Engineering Academy were used. The shearing process implementation with press shears was carried out in a hydraulic press of department. Two symmetrically placed load cells with measurement range of 200 kN (20 t) were introduced to the press shears design in order to estimate the energy and power parameters of a process. The signal from the load cells entered the strain-gauge-type amplifier Topaz-3, followed by processing with analog-digital converter (L-card firm, E-154 model) and introduction into ECM using standard software. General view of used laboratory facility is shown in Figure 2.

The plates of 3, 4 and 5 mm in thickness and 380 mm in width were used as test samples. Chemical composition and mechanical properties of sheared samples are shown in Table 1.

During the experiment, the strips of 22 mm in width were sheared from plates at a toolplate speed 0.6 mm/s using the knives of

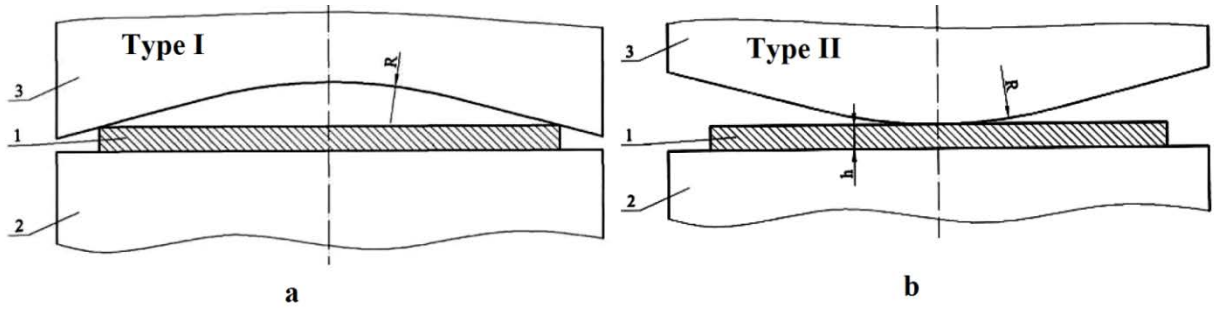
two types (Fig. 3). At that, I-type knives operated with the slope of the knife edges by an angle 3º without rounding off and with 200, 400 and 800 mm rounding off, and also with the slope of the knife edges by an angle 1º without rounding off. The II-type knives operated with the slope of the knife edges by an angle 3º without rounding off and with 100 and 400 mm rounding off, and also with the slope of the knife edges by an angle 1º without rounding off.

a b

Figure 2. General view press shear installed on the press (a) and attached to the measuring system (b)

Table 1. Chemical composition and mechanical properties of sheared samples

Plate thickness, h, mm	Chemical composition, %								Mechanical properties		
	C	Mn	Si	Cr	Ni	Cu	P	S	$\sigma_{0,2}$, MPa	σ_b, MPa	δ_5, %
3	0,20	0,53	0,11	0,05	0,02	0,02	0,030	0,027	277	399	11
4	0,18	0,53	0,11	0,05	0,03	0,06	0,021	0,024	351	413	14
5	0,13	0,3	0,2	0,03	0,02	0,03	0,012	0,019	310	397	22



a b

Figure 3. Knifes execution configuration when implementing of the experiment

As a result of the experiment, the resulting dependences of shearing force were obtained by adding of the indexes of two load cells installed in parallel, and the geometry of the sheared strips was obtained by shear surface profile scanning. In Figure 4, the shearing force dependences (Fig. 4 a) and also sheared strips a general view (Fig. 4 b) and their scanned profiles (Fig. 4 c) are shown using 5 mm thick plates, which are sheared by knives of types I and II with the slope of the knife edges by an angle 3º without rounding off, as an example.

From the images shown in Fig. 4 (b, c), it can be seen that the use of II-type chevron knife allows significant reducing (from 19.8 mm to 2.4 mm) of residual deflection of the strip (Y) after shearing. Moreover, as follows from shearing force graphs (Fig. 4 a), it may increase (to 10%) by using II-type chevron knife which is not critical from the standpoint of shears load.

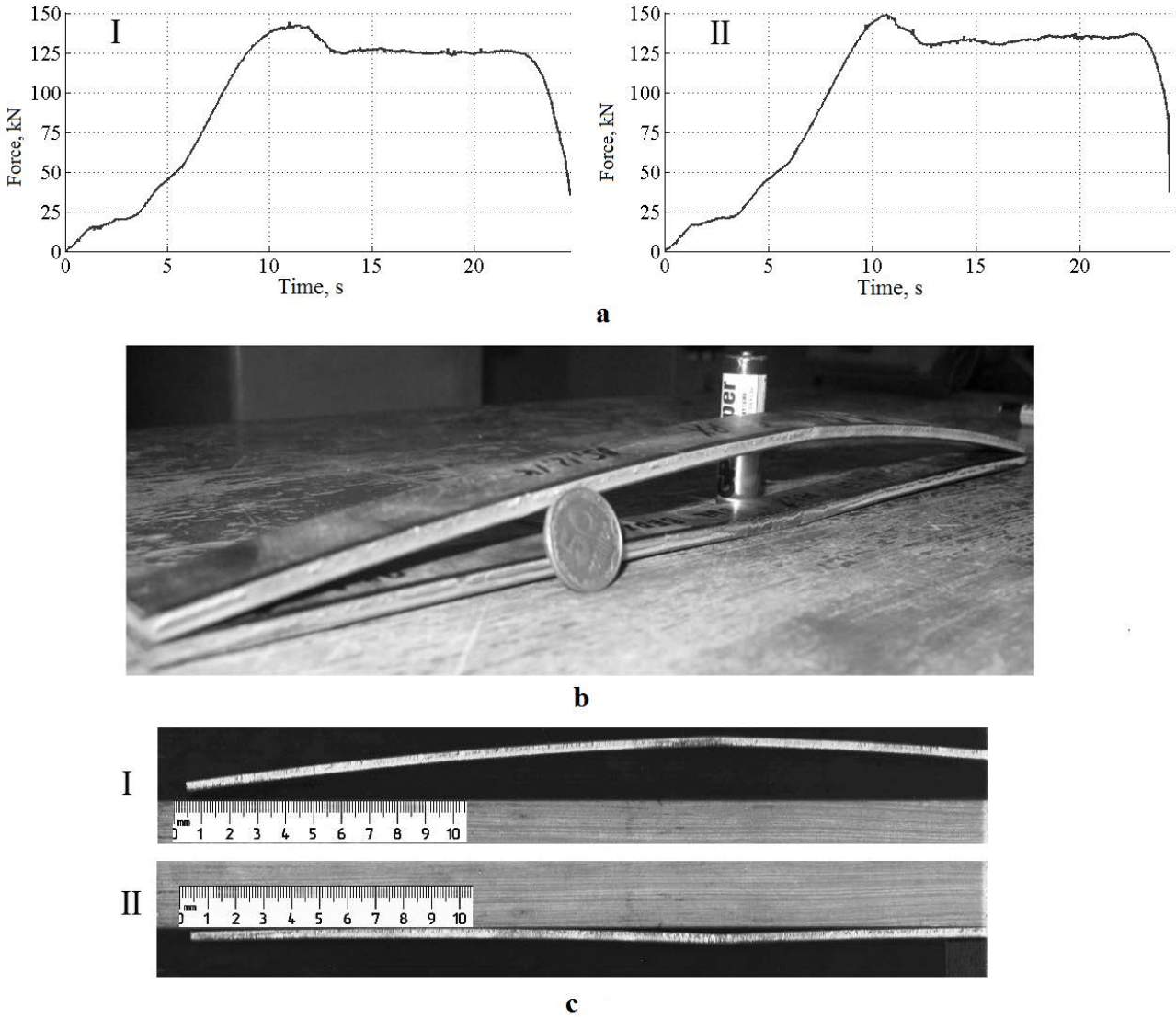


Figure 4. Shearing force dependences (a), sheared strips general view (b) and their scanned profiles (c) using the example of 5 mm thick plates, which are sheared by knives of types I and II with the slope of the knife edges by an angle 3º without rounding off.

It should be noted that residual deflection commensurable quantity can be obtained by using classical form knives (type I without rounding off) with the slope of the knife edges by an angle 1º, but the shearing force increases 2…2.5 times. Furthermore, when using the II-type knife with the slope of the knife edges by an angle 1º, we obtained almost 2-fold reduction of residual deflection under shearing force value commensurable with the I-type knife.

The rounding off radius effect in top of a convergence of knife edges on the ratio of the maximum shearing force F_{max} to steady state F_{st}, and the ratio of residual deflection of strip Y to the sheet thickness h is shown on Figure 5.

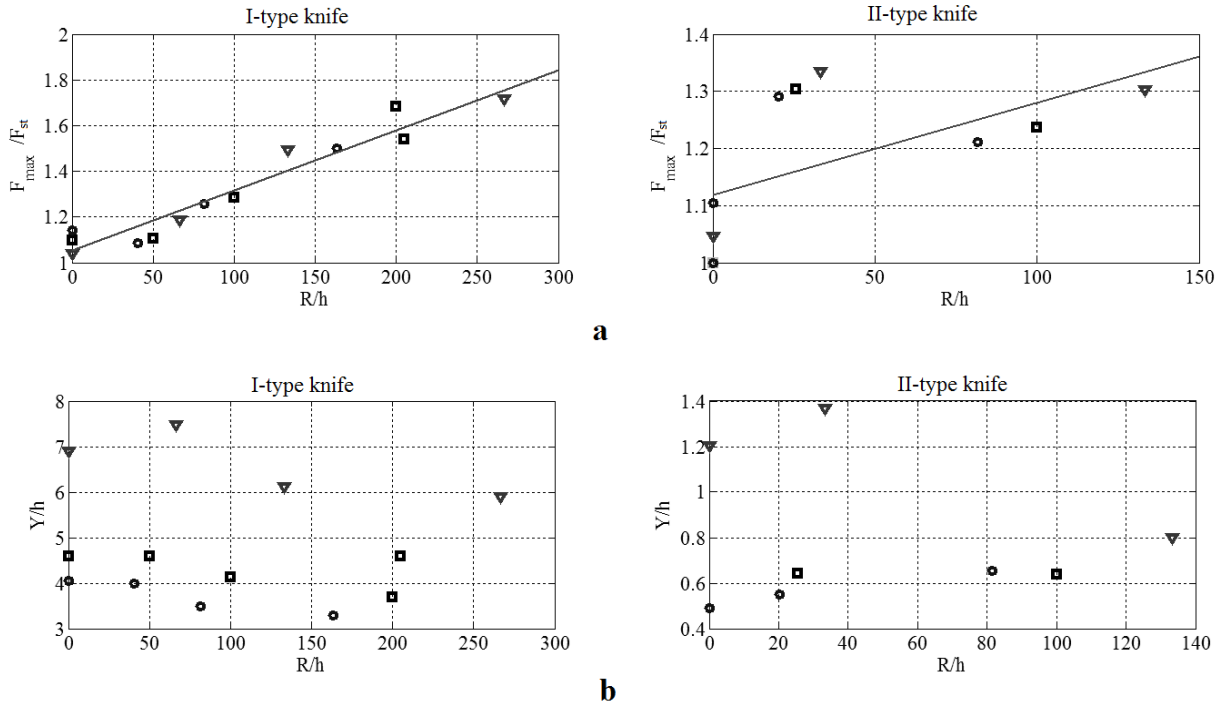


Figure 5. The effect of ratio of rounding off radius in top of a convergence of knife edges to the plate thickness h (for I and II type knifes) on ratio of the maximum shearing force F_{max} to steady state F_{st} (a) and the ratio of residual deflection of strip Y to the sheet thickness h (b) when shearing of sheets of 3 (∇), 4(□) and 5(o) mm thickness

From dependences analysis shown in Figure 5, it can be stated that the maximum value of shearing force increases with rounding off radius increasing for knifes of both types, and the shearing force ratio to the steady state force does not practically depend on the knife type. At the same time, the strip residual deflection reduction may be observed with the increasing in the rounding off radius for the I-type knife, but considering the increasing of maximum force, the absolute value of deflection is enormously larger than the II-type knife. Moreover, it is extremely difficult to assess the effect of the rounding off radius on the strip residual deflection from the presented experimental data for the II-type knife. This is quite explainable, because on the basis of theoretical research in paper [11], it was established that the residual deflection is much more dependent on the sheet width and the sheared material tensile strength (in the conditions of the experiment, the width of the sheared sheet was taken constant and tensile strength had a small spread for significant effect).

Summarizing the results, we can make the following conclusions:

- the chevron type knife with a concave (classical) arrangement of knife inclined planes with profile rounding off in the top of their convergence reduces the residual deflection, but the effectiveness of such a solution is quite small because it is accompanied by nearly 100% increase in the maximum strength while the residual deflection is reduced up to 25%;

- the chevron type knife with a curved (modified) arrangement of knife inclined planes with the possible profile rounding off in the top of their convergence is more effective because if all other conditions being equal allows reducing of the residual deflection by 60 ... 85% while increasing of the maximum shearing force by not more than 10 ... 15% in comparison with classic knife design;

Results of the work can be used for development of the modified chevron type knife design and its implementation into the industrial production.

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