MODELING OF ROLLABILITY OF SURFACE DEFECTS DURING COLD ASYMMETRIC ROLLING

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ABSTRACT

This paper presents the results of finite element modelling of the rollability of the most common surface defects (scratch, puncture, pressure) during cold rolling under symmetrical and asymmetric conditions with an asymmetry coefficient from 1 to 16. A steel strip with a thickness of 3 mm was used as an initial blank. The three surface defects were created on the surface, all defects had a depth of 0.5 mm. It was revealed that complete closure of all the defects studied during symmetrical rolling occurred only when initial blank was compressed by 80 % higher (0.9 mm) than the initial defects depth. When using asymmetric rolling, an additional compression of 20 % (0.6 mm) and an asymmetry level of 8 were required. Thus, asymmetric rolling can be considered an effective way to eliminate surface defects of a cold-rolled strip while providing a significantly lower compression level compared to symmetrical rolling.

Keywords: surface defects, rollability, rolling, modelling.

INTRODUCTION

Rolled sheet metal is a versatile material utilized across diverse industrial sectors, each with distinct quality requirements, including surface quality criteria. The requirements for the surface quality of rolled products are determined by the requirements for the surface quality of products made of sheet steel, as well as by the different purpose of the metal, which is determined by the technology of subsequent processing of sheets, strips, tinplate (stamping, painting, metal coating, etc.). The highest standards are applied to hot-rolled and cold-rolled products intended for the fabrication of various metal products by cold-forming methods, particularly car body parts.

The surface of hot-rolled and cold-rolled strips and sheets is often affected by defects. In many cases, such metal products are rendered unsuitable for effective use in sheet stamping production, since a defect on the sheet surface during its shaping can cause stress concentration in the appropriate place and a sharp increase in the degree of metal deformation, or become a source of metal destruction during further processing. Consequently, in accordance with the GOST 7350-77 and GOST 9045-93 standards, the classification of sheet steel is primarily determined by the presence and characteristics of various defects, encompassing aspects such as appearance, size, microstructure [1, 2].

During the rolling process, these defects undergo changes, with some being rolled out partially or completely, while others persist until the finished profile. The presence of defects can serve as a reason for the rejection of metal due to the inability to use it for its intended purpose. The depth of these defects is a critical factor in determining the quality of the metal surface. In most cases, surface defects are not permitted on the finished product. It was revealed that 91.6 % of defects in metal sheets and strips occur during rolling

conversion, with up to 44 % being formed during hot rolling and 47.6 % during cold rolling [3, 4]. At the same time, research on the elimination of rolled metal defects is carried out in various directions, starting from optimizing the casting process of blanks, and ending with metal forming [5 - 9]. However, it is often not possible to eliminate all surface defects through traditional rolling processes, which results in a decline in the quality grade of the blank, often leading to rejection. Consequently, the search for methods to mitigate the prevalence of surface imperfections has emerged as an urgent task.

One potential solution that has been proposed is the intensification of shear strains during the rolling process. This method has been shown to be effective in various forging processes involving the deformation of large workpieces [10]. The enhancement of shear strains during rolling can be most readily achieved by utilizing the asymmetry factor, whereby the rolling rolls rotate at different speeds, thereby engendering a substantial disparity in kinematic conditions on the upper and lower faces of the workpiece [11, 12]. In recent years, several studies of asymmetric rolling have been conducted, which have proven the effectiveness of this method for grinding the structure and increasing the level of mechanical properties of the processed material [13 - 17]. At the same time, little attention has been paid to improving the surface quality of the rolled metal during asymmetric rolling. The present study aims to utilize finite element modelling to investigate the rollability of surface defects during cold rolling with different levels of asymmetry.

EXPERIMENTAL

To study the rollability process of surface defects during cold asymmetric rolling, it was decided to conduct finite element modelling in the DEFORM software package [18]. Rolling rolls with a smooth barrel with a diameter of 400 mm were used as a deforming tool, which correspond to the asymmetric rolling mill at Nosov Magnitogorsk State Technical University [19]. This mill has an individual drive for each roll with the possibility of creating an asymmetry coefficient of up to 40 due to different rolls rotation speeds. A steel strip with a thickness of 3 mm was used as an initial blank. The three most common surface defects (scratch, puncture, pressure) were created on the surface, all defects had a depth of 0.5 mm. The distance between the defects was 30 mm to avoid any mutual influence. The scratch was represented as a rectangular depression (Fig. 1a), the puncture was represented as a conical depression (Fig. 1b), the pressure was represented as a spherical depression (Fig. 1c).

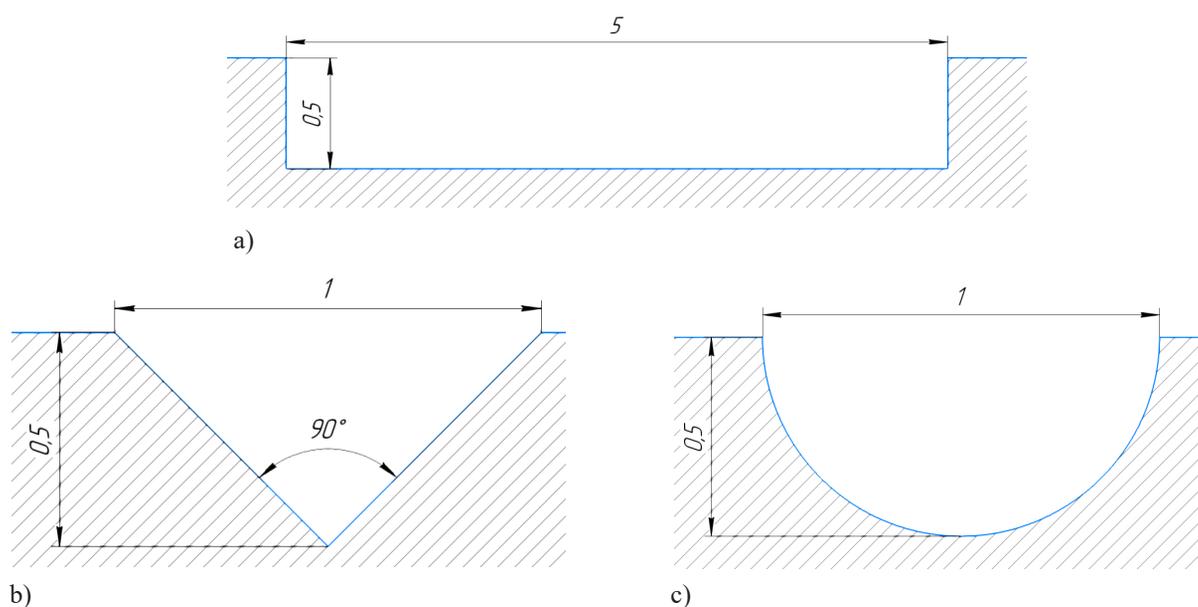The asymmetry effect was created due to the different

Fig. 1. Diagrams of surface defects.

values of rolls rotation speeds. In the symmetrical case, both rolls had a speed of 60 rpm. The asymmetry conditions were modelled with a coefficient of 1.5 (90/60 rpm), 2 (120/60 rpm), 4 (240/60 rpm), 8 (240/30 rpm), 16 (240/15 rpm). In addition, these models were recalculated with a mirror change in rotation speeds to evaluate the effect of the asymmetry direction on the rollability of defects.

The modelling conditions were accepted as follows:

- the type of roll material is rigid; the type of billet material is elastic-plastic;

- the gap between the rolls was 2.5 mm (compression during rolling was equal to the depth of defects 0.5 mm);

- the material of the workpiece is AISI 1010 steel, the temperature of the workpiece is 20°C (hardening curve is shown in Fig. 2);

- the friction coefficient at the contact of the workpiece with the rolls was assumed to be 0.3, which corresponds to the average level of roughness without the use of grease. Even though in conventional cold sheet rolling, the coefficient of friction usually has a value of 0.1 - 0.15, such low values are achieved using lubricants and grinding of the working surface of roll. In this study, it was decided to make the friction level average so that the effect of slipping of the workpiece would not occur during rolling, which would negatively affect the effect of asymmetry. The general view of the model at the initial stage is shown in Fig. 3.

The degree of closure of defects was determined by reducing the value of their area, these measurements were carried out in CAD Kompas-3D by layer image overlay [20].
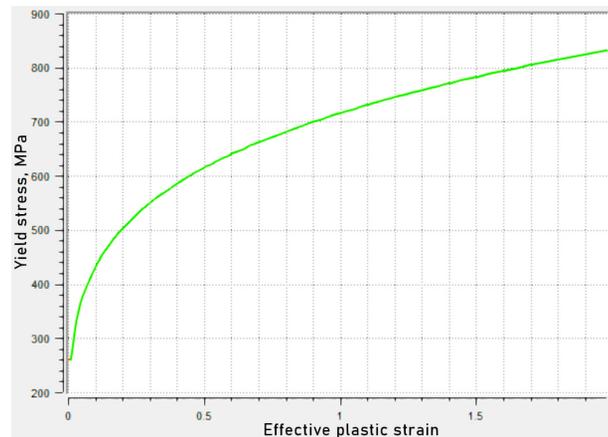

Fig. 2. Hardening curve of AISI 1010 steel at 20°C.

RESULTS AND DISCUSSION

When rolling a sheet billet under symmetrical conditions, the deformation zone is completely symmetrical relative to the horizontal plane of symmetry (Fig. 4).

Under these conditions, the degree of impact of the rolls on the upper and lower faces is the same. However, when the defect passes through the deformation site, this uniformity is disrupted due to the different thickness of the layers. Fig. 5 clearly shows that when the workpiece area is deformed to a defect, the stress level is approximately 550 MPa, while in the defect area the stress level decreases to 370 MPa.

Fig. 6 shows images of defects before and after passing through the deformation zone of rolls.
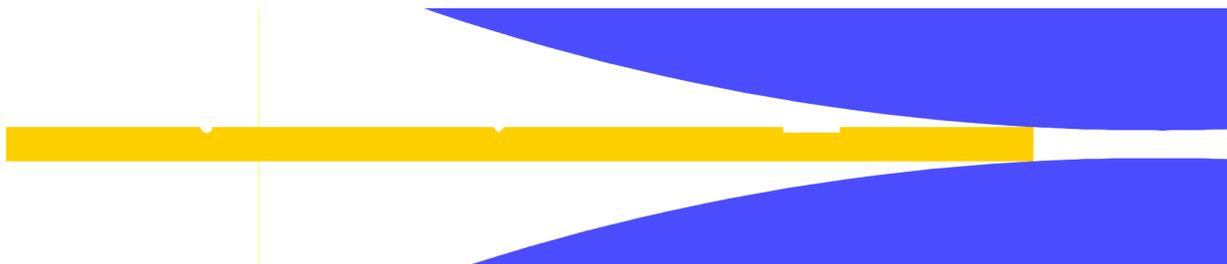

Fig. 3. General view of the model.

During symmetrical rolling, the scratch closed by 92 %, the puncture closed by 56 %, the pressure closed by 74 %. Thus, it can be concluded that rolling with compression equal to the defect depth is an ineffective method for surface defects rollability.

With asymmetrical deformation, an uneven kinematic effect occurs on the workpiece, which manifests itself in a change in the flow velocity of the metal on the upper and lower edges of the workpiece (Fig. 7a, b). When the speeds change in a mirror, the direction of the displacement of the layers along the height of the workpiece changes to the opposite (Fig. 7c, d).
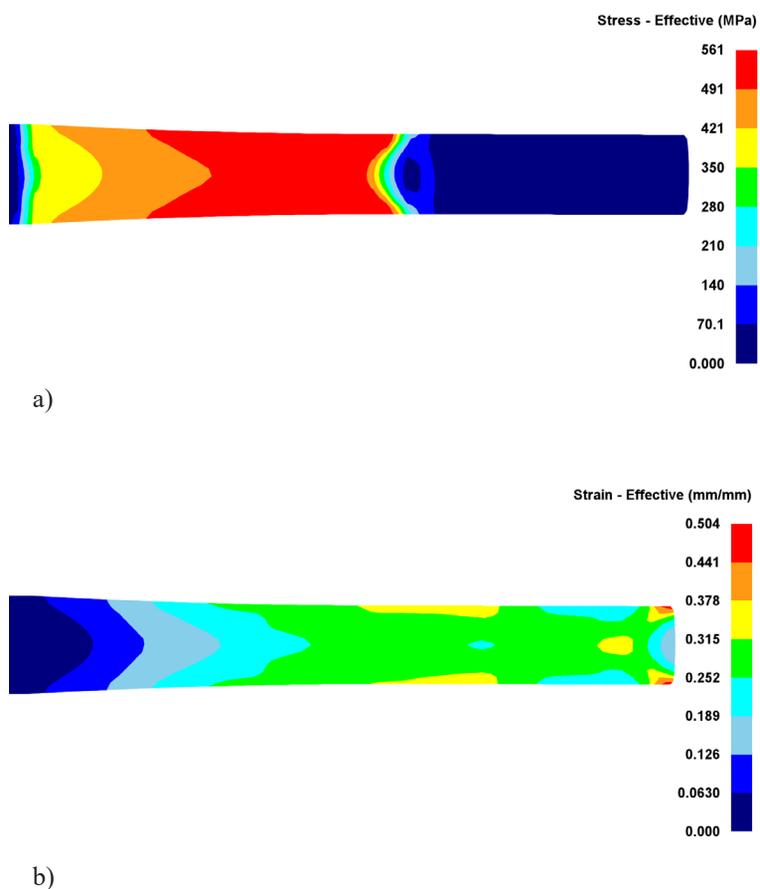

a)

b)

Fig. 4. Deformation zone during symmetrical rolling: (a) - distribution of equivalent stress, (b) - distribution of equivalent strain.
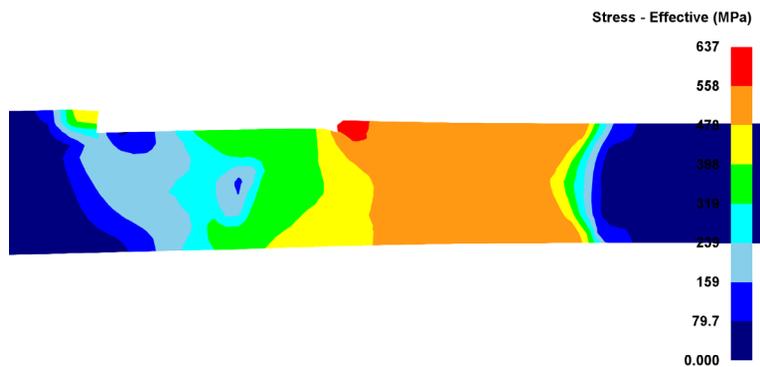

Fig. 5. Uneven stress during deformation of a defect zone.
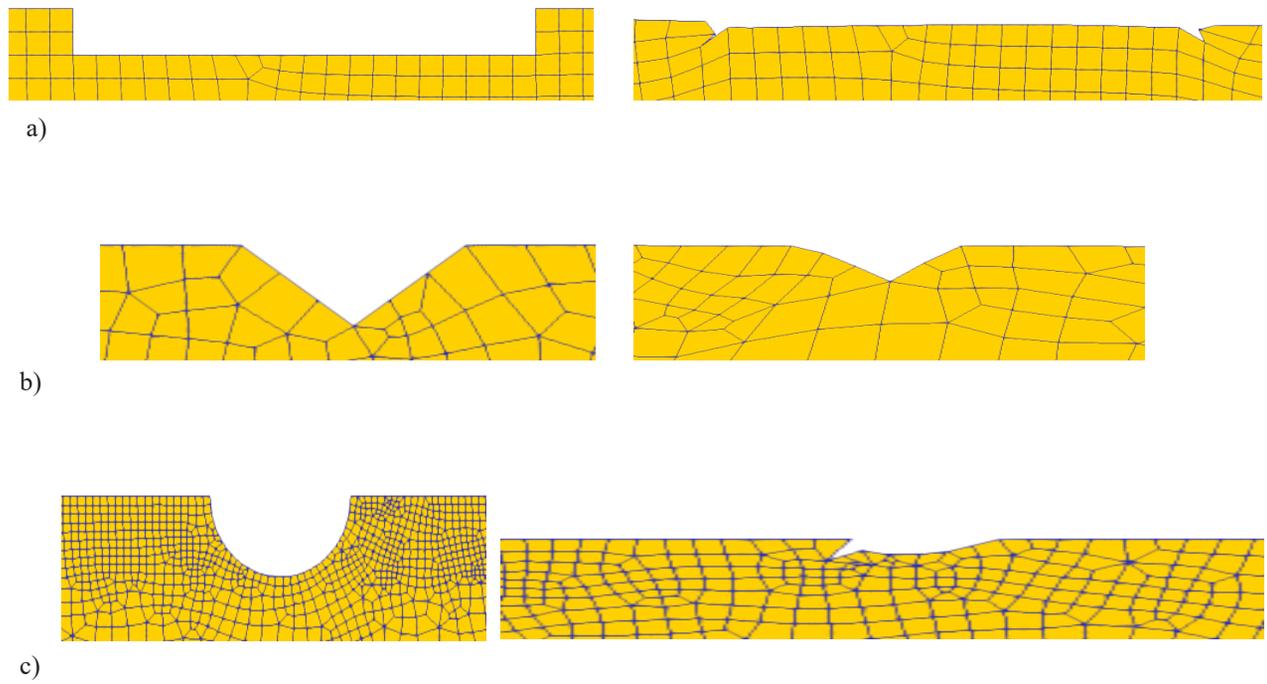
Fig. 6. Closing defects in symmetrical rolling conditions: (a) - scratch, (b) - puncture, (c) - pressure.
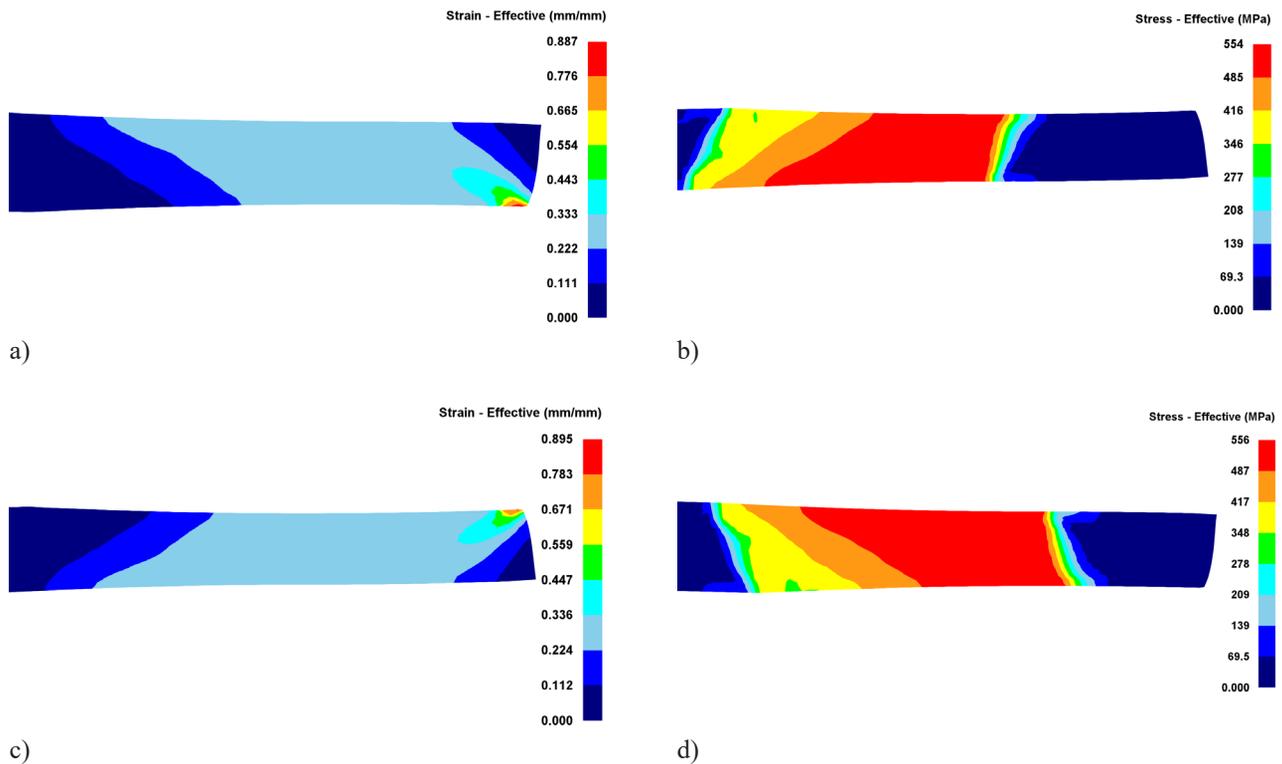

Fig. 7. Deformation zone during asymmetric rolling: (a) - distribution of equivalent stress, model 90/60, (b) - distribution of equivalent strain, model 90/60, (c) - distribution of equivalent stress, model 60/90, (d) - distribution of equivalent strain, model 60/90.

Fig. 8 shows images of defects after rolling with an asymmetry coefficient of 1.5 (90/60 and 60/90).

During asymmetric rolling with an asymmetry coefficient of 1.5, the "scratch" defect was closed by 96 % in the 90/60 model and by 94 % in the 60/90 model. The "puncture" defect was closed by 57 % in the 90/60 model and by 61 % in the 60/90 model. The "pressure" defect was closed by 77 % in the 90/60 model and by 78 % in the 60/90 model. Thus, it can be concluded that

asymmetric rolling with an asymmetry coefficient of 1.5 with compression equal to the depth of defects led to an increase in the rollability of surface defects. However, this level of defect closure is not sufficient to speak about the effectiveness of this method. Therefore, the modelling was continued with the remaining variants of the asymmetry. The summary results of all models are shown in Table 1.

As can be seen from the data in Table 1, an increase
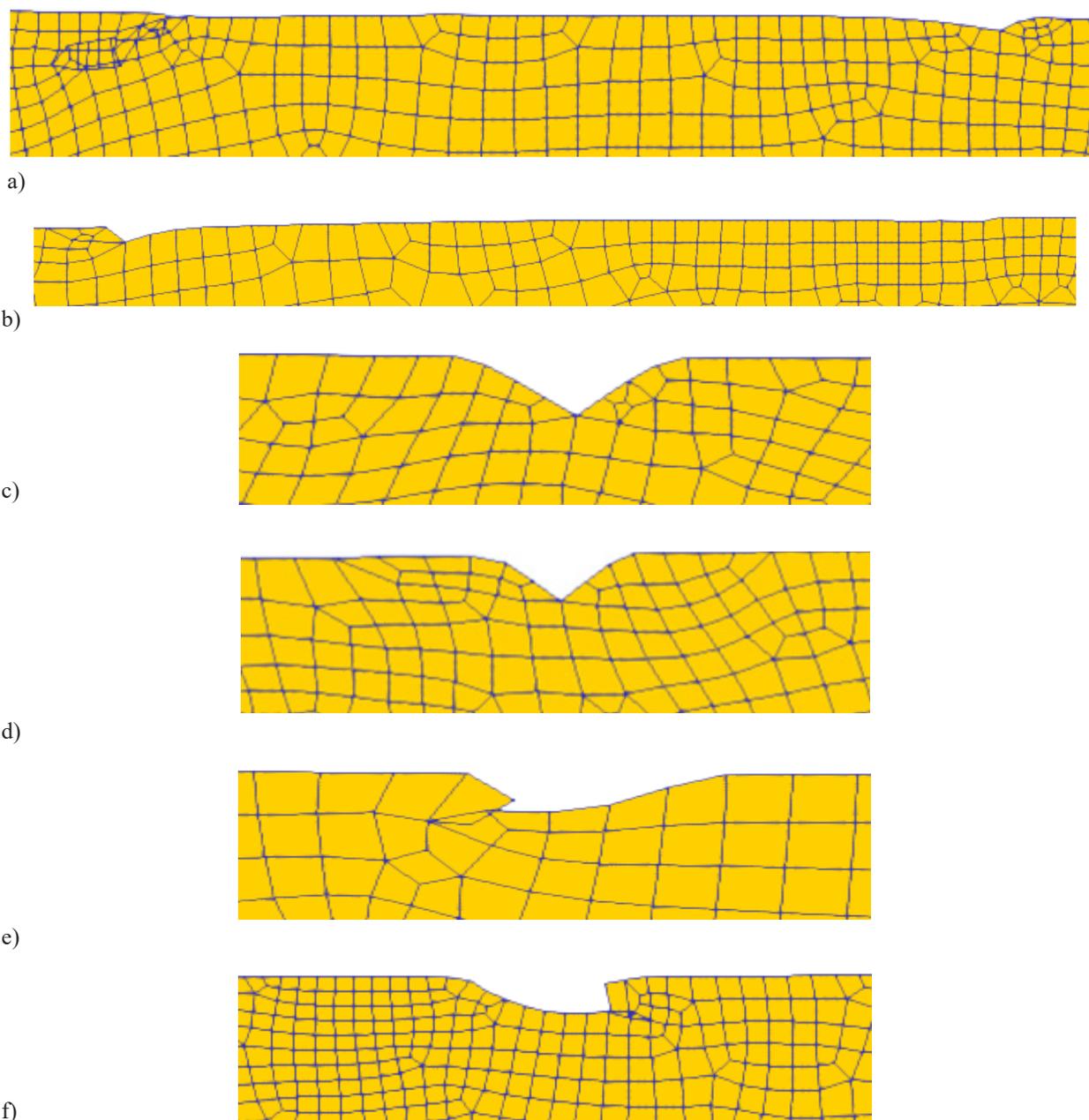

a)

b)

c)

d)

e)

f)

Fig. 8. Closing defects in asymmetric rolling conditions: (a) - scratch (model 90/60), (b) - scratch (model 60/90), (c) - puncture (model 90/60), (d) - puncture (model 60/90), e) - pressure (model 90/60), (f) - pressure (model 60/90).

in the asymmetry level favorably affects the degree of rollability of all the defects studied. However, even with an asymmetry coefficient of 16, only the "scratch" defect is completely closed, the "pressure" defect is 95 % closed, which also indicates the effectiveness of using asymmetric rolling to eliminate surface defects. Asymmetric rolling has the least effective effect on the closure of the "puncture" defect, where the degree of closure of the defect has reached only 80 %. This is a

consequence of the geometric shape of the defect, where the inner corner is a stress concentrator.

It was decided to continue modelling by increasing the compression level to 0.6 mm (i.e., exceeding the depth of defects by 0.1 mm). Table 2 shows the results of rolling out defects under these conditions.

As can be seen from the data in Table 2, an increase in the compression level by 0.1 mm significantly increased the rollability level of all defects, even with symmetrical

Table 1. The degree of defect closure at various asymmetry levels.

Asymmetry coefficient	Roll rotation speeds (upper/lower), rpm	Degree of defect closure, %		
		scratch	puncture	pressure
1	60/60	92	56	74
1.5	90/60	96	57	77
	60/90	94	61	78
2	120/60	97	59	80
	60/120	95	62	81
4	240/60	99	65	85
	60/240	98	66	85
8	240/30	100	74	89
	30/240	99	74	90
16	240/15	100	78	95
	15/240	100	80	96

Table 2. The degree of defect closure at various asymmetry levels with a compression of 0.6 mm.

Asymmetry coefficient	Roll rotation speeds (upper/lower), rpm	Degree of defect closure, %		
		scratch	puncture	pressure
1	60/60	98	77	90
1.5	90/60	99	84	93
	60/90	99	85	94
2	120/60	100	88	96
	60/120	100	88	96
4	240/60	100	95	99
	60/240	100	96	100
8	240/30	100	100	100
	30/240	100	99	100
16	240/15	100	100	100
	15/240	100	100	100

rolling. However, there is no complete closure in this case. It should be noted that the combined effect by increasing the asymmetry level and compression leads to the complete closure of all defects already at an asymmetry coefficient of 8.

The last stage of the simulation was aimed at achieving 100 % closure of defects during symmetrical rolling. In the absence of such result, the use of the asymmetry effect continued, except for the conditions for 100 % closure of defects at the previous stage. At each stage, it was decided to continue increasing the compression by 0.1 mm. The results are presented in Tables 3-5.

Table 3. The degree of defect closure at various asymmetry levels with a compression of 0.7 mm.

Asymmetry coefficient	Roll rotation speeds (upper/lower), rpm	Degree of defect closure, %		
		scratch	puncture	pressure
1	60/60	100	92	97
1.5	90/60	100	95	98
	60/90	100	96	99
2	120/60	100	97	100
	60/120	100	98	100
4	240/60	100	100	100
	60/240	100	100	100

Table 4. The degree of defect closure at various asymmetry levels with a compression of 0.8 mm.

Asymmetry coefficient	Roll rotation speeds (upper/lower), rpm	Degree of defect closure, %		
		scratch	puncture	pressure
1	60/60	100	97	98
1.5	90/60	100	98	99
	60/90	100	100	100
2	120/60	100	100	100
	60/120	100	100	100

Table 5. The degree of defect closure at various asymmetry levels with a compression of 0.9 mm.

Asymmetry coefficient	Roll rotation speeds (upper/lower), rpm	Degree of defect closure, %		
		scratch	puncture	pressure
1	60/60	100	100	100
1.5	90/60	100	100	100
	60/90	100	100	100

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CONCLUSIONS

The complete closure of all the defects studied during symmetrical rolling occurred only when 0.9 mm was compressed, which is 80 % higher than the initial defects depth. When using asymmetric rolling, an additional compression of 20 % and an asymmetry level of 8 were required. Thus, asymmetric rolling can be considered an effective way to eliminate surface defects of a cold-rolled strip while providing a significantly lower compression level compared to symmetrical rolling.

Authors' contributions

E.P.: methodology, investigation, writing - original draft; S.L.: investigation, funding acquisition, project administration; A.N.: conceptualization, methodology, investigation; D.P.: visualization, investigation; A.E.: validation, data curation; N.L.: software; D.K.: writing - review & editing; O.S.: formal analysis, resources.

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