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ANALYSIS OF FRICTION JOINING OF PRESSED GRATING FLATS

ANALIZA TARCIOWEGO POŁĄCZENIA PŁASKOWNIKÓW KRAT PRASOWANYCH

Key words: pressed gratings, friction joining, friction forces.

Abstract The aim of the paper is to analyse the friction forces in joints of pressed platform flat and transverse bars. Actual friction forces could have been determined based on the diagrams of force changes in the process of removal of a transverse bar from a groove in a flat bar. The paper presents diagrams of pressing and removing forces of transverse bars. The measurement of forces has been done for three distances between grooves in flat bars, i.e. 11.1 mm, 22.2 mm, and 33.3 mm. A significant variation of force values has been observed during both pressing and the extrusion of the bars. It has been assumed that one of the main causes of variation is the groove geometry. On the groove, walls there are stamp material shearing areas and breaking areas. The shearing area determines the friction force values.

Słowa kluczowe: kraty prasowane, połączenie tarciowe, siły tarcia.

Streszczenie Celem pracy jest analiza sił tarcia w połączeniach płaskowników nośnych i poprzecznych krat prasowanych. Rzeczywiste siły tarcia można było określić z wykresów zmian sił w procesie usuwania płaskownika poprzecznego z rowka w płaskowniku nośnym. W pracy przedstawiono wykresy sił wprasowywania i usuwania płaskowników poprzecznych. Pomiaru sił dokonano dla trzech odległości rowków w płaskownikach nośnych, tj. 11,1 mm, 22,2 mm i 33,3 mm. Stwierdzono duże zróżnicowane wartości sił zarówno podczas wprasowywania, jak i wyciskania płaskowników. Przyjęto, że jedną z głównych przyczyn powstających różnic jest geometria rowków. Na ściankach rowków występuje strefa ścinania materiału stemplem oraz strefa pękania. O wartościach sił tarcia decyduje strefa ścinana.

INTRODUCTION

Pressed gratings, due to their use, are often called platform gratings. A grating assembled on a production line is an intermediate product. Finished products are bridges, stairs, sewer covers, platforms, fence segments, and other constructions made using these gratings [**L. 1, 2**]. A pressed grating consists of flat and transverse bars. They are joined by pressing transverse bars into the grooves of flat bars. That kind of joining is also known as "cold welding." The stages of the process are shown in **Fig. 1**.

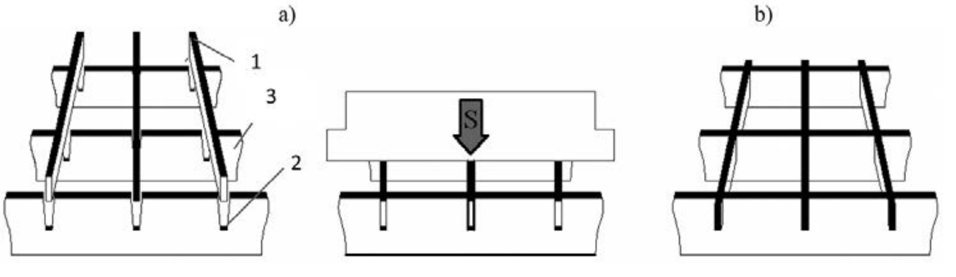

Fig. 1. Stages of joining of pressed grating flats: a – transverse bars (1) before pressing into grooves (2) located in flat bars (3), b – assembled grating

Rys. 1. Etapy łączenia płaskowników krat prasowanych: a – płaskowniki poprzeczne (1) przed wprasowaniem w rowki (2) znajdujące się w płaskownikach nośnych (3), b – krata zmontowana

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A lasting joining of both flats should be guaranteed by friction forces. During the calculation of grating load capacity, the quality of flat joining is not taken into account [**L. 3, 7**]. In practice, the friction force values are varied. The friction force value in a particular pressed grating depends indirectly on the mutual dimensional tolerance of the groove in a flat bar, the geometry of the groove, and the plastic characteristics of both flats [**L. 4**]. In borderline cases, their lack on some of the nodes prevents further technological process stages to be performed due to geometrical instability. Further processes are the corrosion protection (usually galvanization), frame assembly, or giving form to the grating corresponding to its use.

The aim of the paper is to analyse the friction forces in the joining of flat and transverse bars of pressed grating.

PROBLEM ANALYSIS

Standard pressed gratings are made of a common construction steel S235JR. The initial material for a flat bar production is a steel sheet supplied in coils from which the bars are cut to a required width. After the bar straightening stage, the grooves are made using a cooperating stamp and matrix [**L. 5**]. Depending on the grating purpose, they are made as a standard in the different distances, i.e. 11.1, 22.2, and 33.3 mm (**Fig. 2**). The transverse bars are made by rolling a bar of a circular profile. The grooves in flat bars can have various shapes (**Fig. 2**). In the paper the subject of consideration will be the groove shown of **Fig. 2c**.

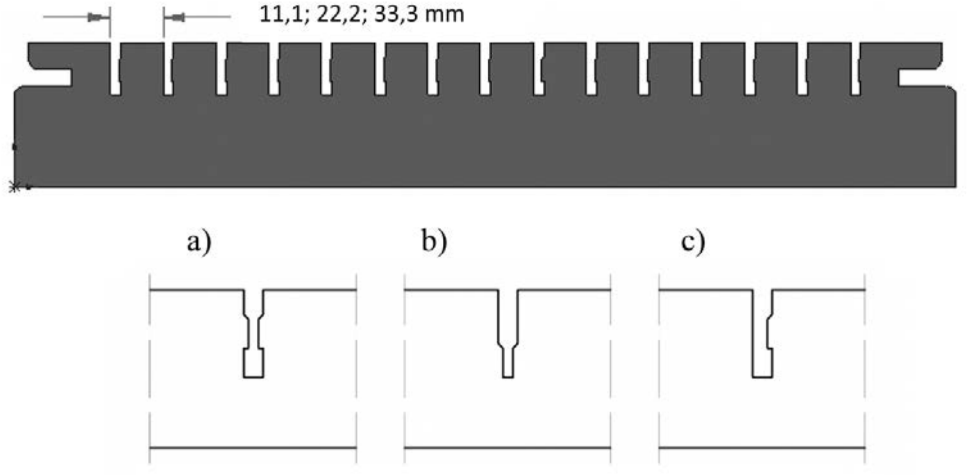

Fig. 2. Diagram of flat bar with grooves; a), b), c) the outline of the grooves used
Rys. 2. Schemat płaskownika nośnego z rowkami; a), b), c) schemat stosowanych rowków

The characteristic property of stamp-matrix extrusion is the wearing out of working surfaces of the stamp and matrix due to frictional resistance [**L. 6, 8**]. It results in a larger clearance between these elements. As a consequence, the distance between groove walls gets larger. The groove surface has two distinctive areas. The first one is connected with the shearing during plastic flow, and the second one with cracking of material. The distances between groove walls are larger in material cracking areas (**Fig. 3**).

The friction forces between flat and transverse bars are specific to each groove shape (**Figs. 2a, b, c**). In all cases, the friction will occur on the surfaces (1) formed during the plastic flow of material (**Fig. 3**). For a groove shape (a, c) in **Figure 2**, they will be the same on both sides of a flat bar and different for a groove shape (b) due to the size of the friction surfaces on both sides of the groove. In the (b) case, the transverse bar adheres along its entire height into the left wall of the groove;

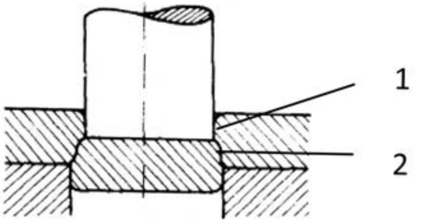

Fig. 3. Diagram of groove surface shaping in a flat bar during: 1) plastic flow, 2) cracking
Rys. 3. Schemat kształtowania powierzchni rowka w płaskowniku nośnym podczas: 1) plastycznego płynięcia, 2) pękania

whereas, on the right side, the contact between the flats will occur only on the narrowing of the distance between walls. A diagram of the forces acting in the process of pressing the transverse bar into an exemplary groove of flat bar is shown on **Fig. 4**. The measured difference between the groove and transverse bar in the narrowing area is 0.2 mm.

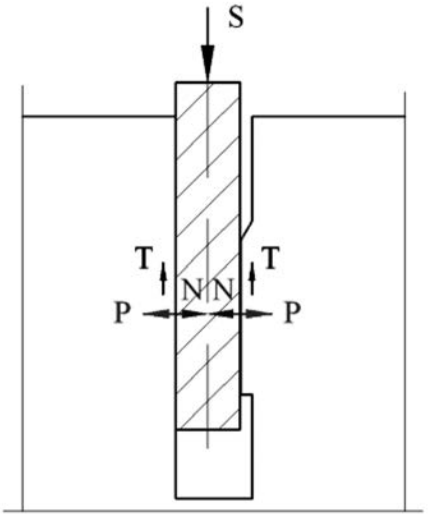

Fig. 4. Diagram of forces present during the pressing of transverse bar (1) into flat bar (2). S – pressing force. T – friction force, N – flat bar wall reaction, P – the force of transverse bar acting on flat bar

Rys. 4. Schemat sił towarzyszących wprasowywaniu płaskownika poprzecznego (1) w nośny (2). S – siła wprasowywania, T – siła tarcia, N – reakcja ścianki płaskownika nośnego, P – siła oddziałania płaskownika poprzecznego na nośny

Due to the forces shown, the grating may be prone to deformations during the production process in both flat bar surfaces and the grating surface, and it can be twisted [**L. 4**]. That kind of grating deformation makes it difficult to process it further, because the construction elements made from it are flat. While joining the flats, the S force (**Fig. 4**) has to overcome friction forces T, and the forces shearing irregularities on the flat bar. Therefore, it needs to be expected that, when the flat bar is removed from the joint, the S force (with opposite direction than on **Fig. 4**) will be smaller. Its maximum value will be equal to friction force determining the durability of the flat joint on that technological stage of railing production.

EXPERIMENTAL STUDY

The aim of the experimental study is to indicate the actual values of friction forces in the joints connecting the flats as well as to indicate the factors affecting their diversity. Tests were carried on samples of flat and transverse bars with a length of 30 cm, acquired directly for the assembly line of railing producer. The material the flats were made of was to be steel S235JR. Flat bars with the cross-section of 3 × 30 mm had grooves (**Fig. 2c**) placed at distances of 11.1, 22.2, and 33,3 mm. The width of grooves in the narrowing area was 1.9 mm. Transverse bars with the cross-section of 2 × 10 mm were produced by rolling the bar with a circular cross-section. Trials of assembly and disassembly of flat bars with transverse bars were performed on the same durability testing machine (**Fig. 5**). Mutual relocation of bars and the force necessary to do it was registered as well.

Fig. 5. A view of flats during connection

Rys. 5. Widok płaskowników kraty podczas ich łączenia

TEST RESULTS AND ANALYSIS

The flat and transverse bars had a history of straining before joining. The flat bar has been strained plastically several times during unrolling of the coils, rolling them again, and unrolling and straightening before the cutting of the grooves. Transverse bars have been subjected to strain hardening during bar rolling. There was a change of mechanical properties in both bars; therefore, it was decided to specify them by performing tensile testing in accordance with the EN-EN 10002-1:2002 standard. Toughness tests of transverse and flat bars, for each of three groove distances, were performed on three samples. Tensile testing was performed using a durability testing machine MTS 858. An example of tensile curves for a distance of 22.2 mm is shown in **Fig. 6**. The overall results of tensile testing are shown in **Table 1**.

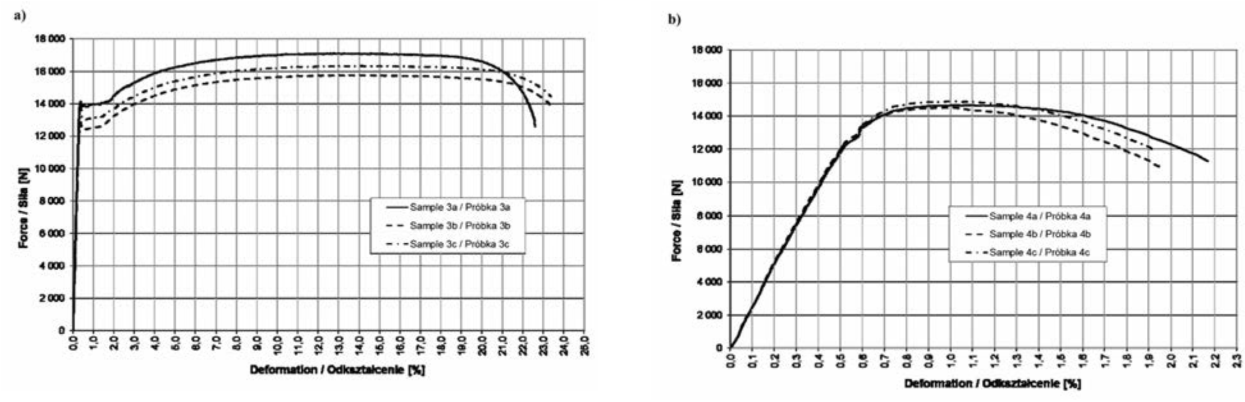

Fig. 6. The result of flats tensile testing: a) flat bar with a groove distance of 33.3 mm, b) transverse bar
Rys. 6. Wynik próby rozciągania próbek płaskowników: a) nośnego z rozstawem rowków 33.3 mm, b) poprzecznego

Table 1. Overall results of tensile strength and yield strength of flat and transverse bar samples
Tabela 1. Zestawienie wytrzymałości na rozciąganie i granicy plastyczności próbek płaskowników nośnych i poprzecznych

Sample marking		Tensile strength R_m [MPa]	Yield strength R_e [MPa]	Arbitrary yield strength $R_{0,2}$ [MPa]
Samples with a 11.1 mm groove	a	372	354	–
	b	385	323	–
	c	386	328	–
	average	**381**	**326**	–
Samples with a 22.2 mm groove	a	394	324	–
	b	389	325	–
	c	395	323	–
	average	**393**	**324**	–
Samples with a 33.3 mm groove	a	402	332	–
	b	372	304	–
	c	383	325	–
	average	**386**	**320**	–
Transverse bar samples	a	844	–	796
	b	833	–	775
	c	850	–	795
	average	**842**	**–**	**789**

Tensile testing results shown on **Fig. 6** and Table 1 indicate that the steel used in flat bar production has a higher yield strength R_e in relation to expected value (R_e = 235 MPa) specified in the standard for steel S235JR. Tensile strength is within the standard, which is expected at values R_m = 360–510 MPa. Higher yield strength is an effect of strain hardening occurring in the technological process of achieving an expected shape of a flat rod. The effect of hardening is not identical for all samples. The material retains a distinct yield strength and a range of plastic flow.

The steel used in the production of transverse bars does not show a distinct yield strength. The arbitrary yield strength $R_{0,2}$ and tensile strength significantly exceed analogical values in flat bars. It is to be expected that, during the pressing of transverse bar into flat bar, a shearing of irregularities on groove walls will occur.

Figures 7 and **8** show the relation of the force of pressing and the extruding of the flat bar and its relocation. Five consecutive flat bars were pressed with the groove distance of 22.2 mm.

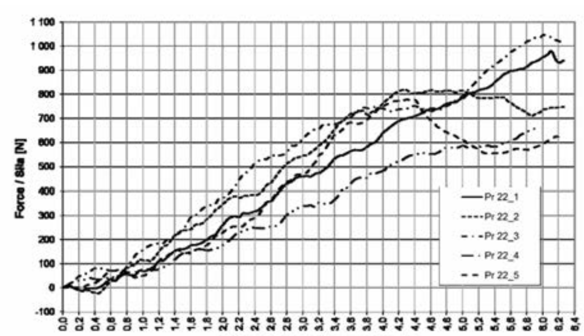

Fig. 7. The course of pressing force of 5 transverse bars into consecutive grooves of a flat bar; groove distance 22.2 mm
Rys. 7. Przebieg siły wciskania 5 płaskowników poprzecznych w kolejne rowki płaskownika nośnego; rozstaw rowków 22,2 mm

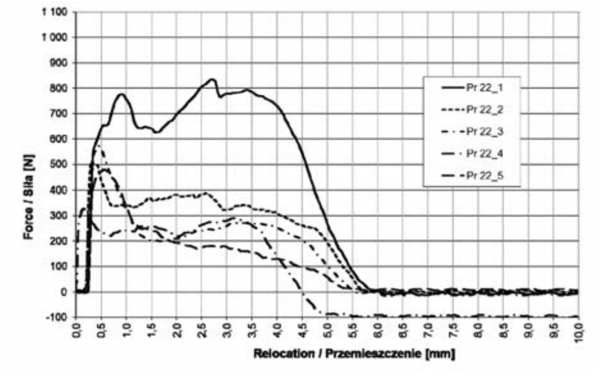

Fig. 8. The course of disassembly force of 5 transverse bars from consecutive grooves of a flat bar; groove distance 22.2 mm

Rys. 8. Przebieg siły demontażu 5 płaskowników poprzecznych z kolejnych rowków płaskownika nośnego; rozstaw rowków 22,2 mm

Similar diagrams were acquired for the remaining groove distances, i.e. 11.1 and 33.3 mm. The course of the acquired diagrams defines changing values of forces in line with a moving stamp. The maximum values of forces reached during the pressing of transverse bars are much higher than the forces needed to disassemble them. During the pressing, the friction forces and the forces of shearing of irregularities in grooves had to be overcome. During disassembly, it was assumed that only friction forces determined the endurance of joining of both flats. **Table 2** compiles the values of friction forces reached during the pressing of transverse bars into 5 consecutive grooves in flat bars.

While analysing the values of friction forces acting in particular bars, it should be noted that their spread is significant. It may be caused by the irregular shape of the groove developed during the cutting process. **Fig. 9** shows a photograph of the shape of the groove in a flat bar. There

Table 2. Values of friction forces in particular samples of flats with groove distances of 11.1, 22.2, and 33.3 mm

Tabela 2. Wartości sił tarcia dla poszczególnych próbek płaskowników z rozstawem rowków 11,1, 22,2, 33,3 mm

		Friction force T [N]]	Average value T [N]
Flat 11.1	Sample 1	217.918	228.08
	Sample 2	278.211	
	Sample 3	201.553	
	Sample 4	360.038	
	Sample 5	82.688	
Flat 22.2	Sample 1	832.911	544.54
	Sample 2	508.188	
	Sample 3	572.788	
	Sample 4	329.030	
	Sample 5	479.764	
Flat 33.3	Sample 1	399.660	509.19
	Sample 2	949.192	
	Sample 3	628.775	
	Sample 4	99.054	
	Sample 5	469.279	

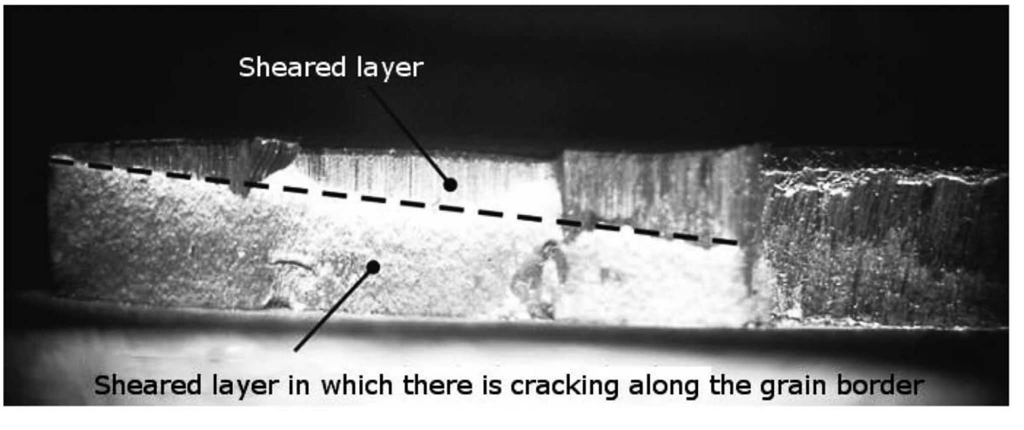

Fig. 9. A view of a groove wall in a flat bar

Rys. 9. Widok ścianki rowka w płaskowniku nośnym are two areas typical for cutting using the stamp-matrix method. On the stamp side there is a sheared layer, and on the matrix side there is a layer created by cracking along the grain border.

During the pressing of transverse bar, the removal of irregularities occurs only in the sheared area, because the distances between groove walls are bigger in the cracking area. The size of both areas in grooves varies. This results in varied values of pressing forces and friction forces in particular tests (**Table 2**). It is worth noting that the values are particularly low in Sample 5 (flat 11.1 mm) and in Sample 4 (flat 33.3 mm). This may happen when, during cutting of the groove, a significant deformation in the narrowing area occurs. The lowest friction forces were acquired with the distance between grooves of 11.1 mm. It may be a result of a higher susceptibility to bending of a flat bar fragments located between particular grooves with a distance of 11.1 mm in comparison to distances of 22.2 mm and 33.3 mm.

CONCLUSIONS

The analysis of test results of friction joining of pressed grating flat and transverse bars allows the following conclusions to be drawn:

- Plastic characteristics of flat and transverse bars are different, with yield strength R_e of transverse bars being twice as high as flat bars.
- The pressing forces of consecutive transverse bars with the same groove distance have a varied course, and their values are a result of overcoming friction forces and removing irregularities by the transverse bar in the area created by stamp shearing in a flat bar.
- Friction force values acting in a particular node joining the flats corresponded to forces determined during the removal of transversal bar.
- The diversity of friction forces with a particular groove distance is attributed to the geometry of the groove in the area created while shearing with the stamp.
- Friction forces were the lowest with a groove distance of 11.1 mm, which may be a result of a higher susceptibility to bending of flat bar fragments located between particular grooves with the distance of 11.1 mm in comparison to distances of 22.2 mm and 33.3 mm.

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REFERENCES

1. Aprobata Techniczna ITB AT-15-3937/2011, Stalowe kraty pomostowe oraz stopnie schodów Mostostal, Wydawnictwo Instytutu Techniki Budowlanej, Warszawa 2011.
2. Aprobata Techniczna ITB AT-15-5259/2014, Stalowe kraty pomostowe i stopnie schodów TERMETAL, Instytut Techniki Budowlanej, Warszawa 2014.
3. Sondej M.: Kraty pomostowe w ujęciu norm i obliczeń numerycznych [Numerical analysis and design codes of steel gratings], Zeszyty Naukowe Politechniki Gdańskiej, Inżynieria Lądowa i Wodna I, 625, (2012), s. 107–117.
4. Szybka M.: Politechnika Białostocka, Wpływ kształtu rowka w płaskownikach nośnych na jej odkształcenia, Praca dyplomowa, Białystok 2005.
5. Hadasik E., Pater Z.: Obróbka plastyczna. Podstawy teoretyczne, Wydawnictwo Politechniki Śląskiej, Gliwice 2013.
6. Lenik K., Korga S., Kalinowska-Ozgowicz E.: Determination of the frictional resistance in the model forming process by the finite element method, Tribologia 5/2017 (275), pp. 29–36.
7. Vaz JR. M., Divo Bressan J.: A computational approach to blanking processes, Journal of Materials Processing Technology, 125–126, 2002, pp. 206–212.
8. Czyżewski P., MoszczyńskI P., Osowski S., Makareiwcz T.: Ocena stanu stempla w procesie wykrawania, Przegląd Mechaniczny, Z 11, 2009, s. 30–31.