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THE ANALYSIS OF RECTANGULAR CLINCHING JOINT IN THE SHEARING TEST

ANALIZA ZNISZCZENIA PROSTOKĄTNEGO ZŁĄCZA PRZETŁOCZENIOWEGO W PRÓBIE ŚCINANIA*

This paper presents the results of experimental researches on effect of clinching joint's load direction change on its characteristics and the maximum shearing force value. The single-folded clinching joints made of aluminum sheet AW1050A have been the subject of researches. Properly prepared specimens of rectangle clinching joints with material notch have been shear tested on the tensile testing machine UTS 100. The extreme joint destruction have been analyzed for the layout angle β = 0°, 90°. The separation mechanism has been described for all angle values β = 0°, 30°, 45°, 90°. The total separation work by joint shearing has also been mentioned.

***Keywords:** clinching joints, shearing, joint separation.*

W pracy zawarto wyniki badań eksperymentalnych dotyczących wpływu zmiany kierunku obciążenia przetłoczeniowego złącza na przebieg charakterystyki i maksymalną wartość siły ścinania. Przedmiotem badań były jednozakładkowe połączenia przetłoczeniowe blach z aluminium AW1050A. Odpowiednio wykonane próbki prostokątnych połączeń przetłoczeniowych z nacięciem materiału poddano testom ścinania na maszynie wytrzymałościowej UTS 100. Przeanalizowano skrajne przypadki zniszczenia złącza dla kąta ułożenia β = 0°, 90°. Opisano mechanizm rozdzielenia połączenia dla wszystkich wartości kąta β = 0°, 30°, 45°, 90°. Zwrócono również uwagę na wielkość całkowitej pracy rozdzielenia przez ścinanie złącza.

***Słowa kluczowe:** połączenia przetłoczeniowe, ścinanie, rozdzielenie złącza.*

1. Introduction

When using the rectangle clinching joints, the awareness of their static strength is extremely important. This enables e.g. to determine load values and types, for which the joint can be used. The most frequently considered parameter is the shearing resistance [4, 5, 6, 7, 11, 12].

The strength (and resistance) of rectangular joint on externally applied shearing load is not identical due to a merging area shape [2, 3, 8, 13, 14]. This depends on its location in relation to the main load direction (see fig. 1).

When mounting sheet elements, the line of locally cut material may be parallel (fig. 2a) or lateral (fig. 2b) to the merging seam line. It is preferred that the main joint load direction coincides with the direction of the highest joint load-carrying ability. In practical conditions, usually it is not possible to locate the direction in that way. The use of clinching joint technology is justified by the capability of its adaptation that the tool access is guaranteed to achieve the tool adequate support rigidity and its retraction after the process [15].

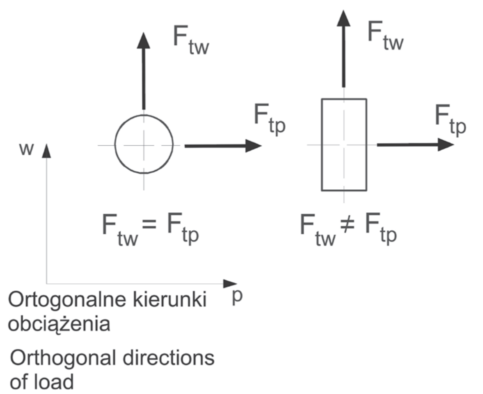

Fig. 1. The cases of rectangle and circular shearing of clinching joint

The awareness of rectangular clinching joint strength and related issues enables selecting proper forming process parameters and determining correct operating conditions. The knowledge on destruction mechanism plays a crucial role when designing and using these joints [10].

Most of available papers is related to clinching joint issue. Only some of them deal with rectangular joints. Recently only some researches, including joint load direction change, have been conducted [2, 3, 8, 13, 14]. One of a few papers [2], related to clinching joint strength analysis, presents the description

a) b)

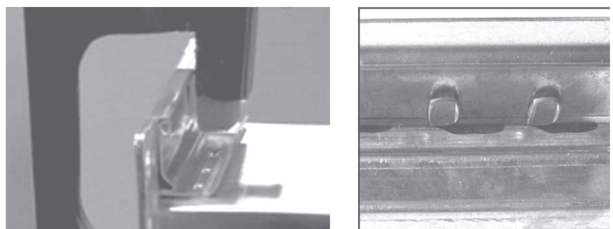

Fig. 2. Overpress joining of HVAC pipe elements made of a steel sheet: a) with a longitudinal seam layout, b) with a perpendicular seam layout

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** of clinching joint static shearing test. Other publications [13, 14], also interesting from this point of view, present the difference of work to be made when destruction testing circular and rectangular joints of various layouts in relation to the principal direction of joint strain. On the other hand, the authors in another publication [8] have presented the effect of joint layout change in nodes of spatial design made of thin sheet profiles on value and characteristics of a force that forces the design deformation. The paper describing the rectangular clinching joint with various layouts in the sheet construction of a controlled crush zone [1] is also worth of interest. The specified joint layout in such components also effects their separation [2].

In this paper, the author has presented the analysis of effect of the joint layout angle (in relation to the load) on the critical value of force separating the joint. Moreover, the author has performed the analysis of destruction of correspondingly loaded joints.

2. The matter of joint forming

The joining process (along with material notching) is performed using tools specifically designed for this method, i.e. the punch of desired shape and the die with segments. These segments may be pressed using the sleeve made of high strength elastomer or flat or coil springs [6].

The joint forming process may be divided into three main phases: I – notching (notching along with prestamping); II – stamping; III – pressing (restriking the overpress bottom) – see fig. 3.

When the punch is being immersed, the material is cut in the point of sheet and die cutting edge and the material fractures and separates in the end of stamping – phase I. The achieved material notches occur along the die cutting edges and facilitate the further stamping process. Then the sheet stamping occurs – phase II. This phase has a short duration and occurs right after the complete material cut and before the overpress bottom pressing. The further punch displacement presses the bottom material and its pressing - phase III. The material cutting, but on quite a lower level, accompanies also the bottom pressing. The radial material flow (fig. 3a) and die segment displacement is caused by the punch pressure on the overpress bottom. This is how the „lock" is created, i.e. seizing the upper sheet material in the lower one. Once the desired sheet merging effect is achieved, the joint forming punch is retracted.

The rectangular clinching joint technology enables joining two (fig. 4a), three (fig. 4b) and even more material layers.

3. The scope and methodology of experimental researches

The commonly available aluminum sheet AW1050A has been used to examine the effect of merging area layout angle in relation to the displacement deforming the joint on its critical load values. The experimental researches have been conducted on the specimens prepared as follows: sheet strips, width of 40 mm and length of 110 mm, cut from the sheet of thickness 1.00±0.05 mm. The material properties are as follows: the agreed yield stress $R_{p0.2}$ = 25 MPa; strength limit R_m = 75 MPa; Young module E = 69 000 MPa; relative elongation A_{50} = 25 mm.

The sheet strips have been joined using tools of specified geometry (fig. 5), mounted on the hydraulic jaw device, while maintaining specified dimensions of finished specimen (fig. 6).

Depending on the punch and die geometry, various maximum pressure force to temporary shearing strength ratios may be achieved. However, single set of tools and single final over-

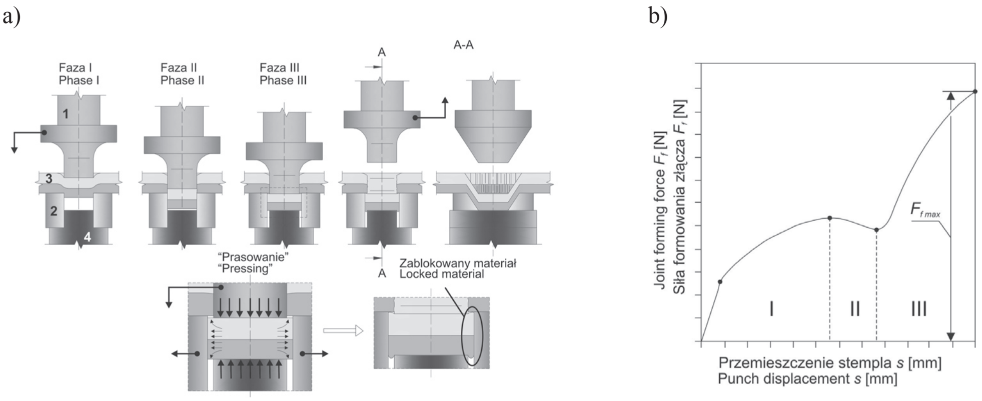

Fig. 3. Forming the rectangular clinching joint with material notch: a) diagram, b) forming force characteristics

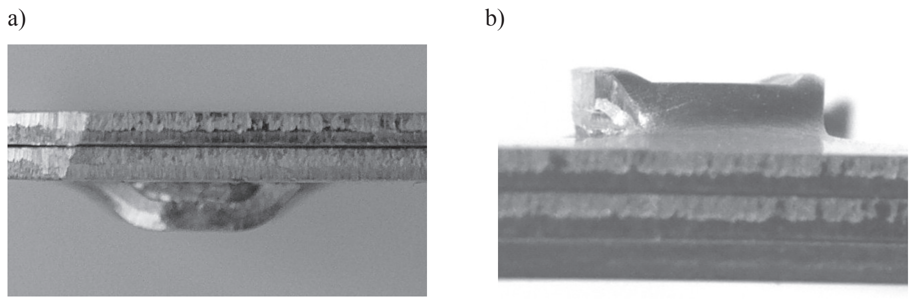

Fig. 4. Merging: a) two material layers, b) three material layers

press thickness (X) have been used in the initial experimental analysis.

When preparing the joint specimens, the merging area geometry layout angle β (fig. 6) has been the only variable parameter, others have been constant. For all cases, the overpress bottom thickness (X) has been of 0.85±0.02 mm.

The key differentiator of clinching joints is the occurrence of specified sheet material seizing in form of lock. The achieved specimens had the characteristic overpress (fig. 7a) and the flash in the merging point (fig. 7b). The specific form of joined material layers (fig. 7c, d) has been achieved thanks using the 2-segment flexible die.

The sheet joints for shearing tests have been properly marked. Such prepared joints have been subjected the shearing strength tests until complete separation. Three specimen series have been examined for four layout angles β. For each one, the force and displacement parameters have been recorded on the tensile testing machine UTS 100. The cross sections of joint have been cut using the wire erosion machine. This enabled to eliminate additional joint deformations, which occur for other cutting methods.

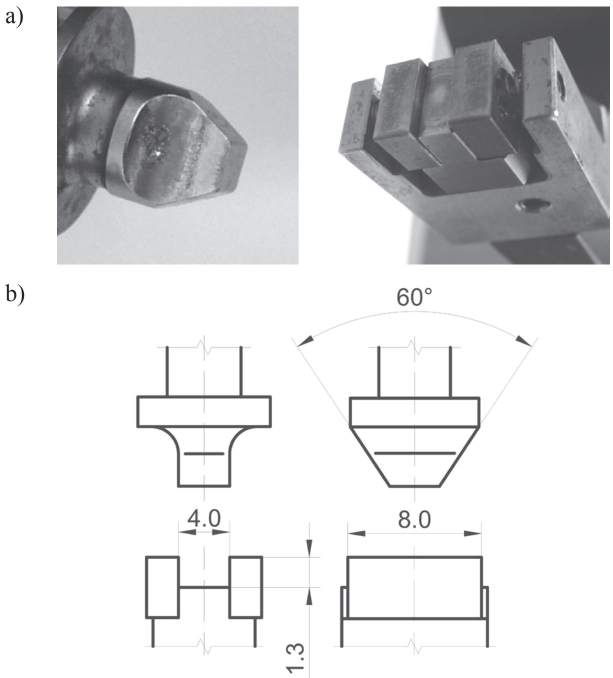

Fig. 5. Joint forming tools: a) appearance of a forming punch and segment flexible die, b) basic geometry

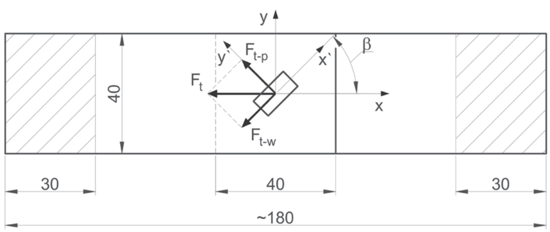

Fig. 6. The characteristics of merging area layout and shearing test specimen geometry

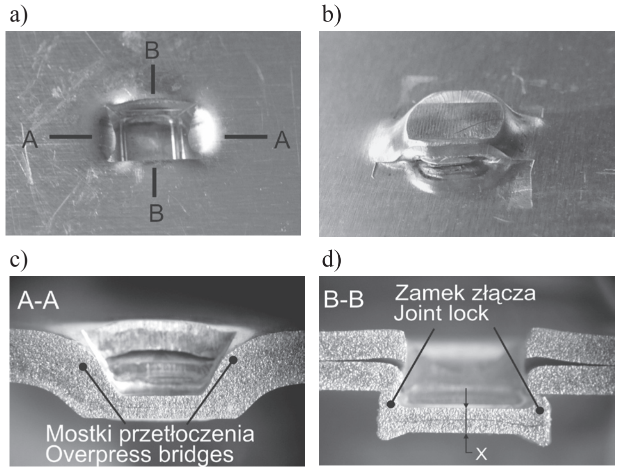

Fig. 7. Joint view: a) the overpress side, b) the flash side, and c) and d) specified cross sections

4. Results and analysis

For circular joints, the load-carrying ability is an isotropic feature. Slight differences in the shearing force characteristics are achieved for highly anisotropic sheets [9]. On the other hand, the rectangular joints feature the anisotropy for load carrying depending on its direction (fig. 8).

For examined cases of joint layout angle $\beta = 0^o, 30^o, 45^o, 90^o$ different force characteristics have been achieved (fig. 9).

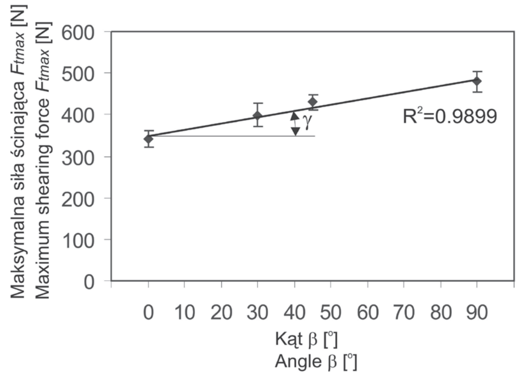

Fig. 8. The effect of layout angle β in relation to applied load direction on maximum shearing force value

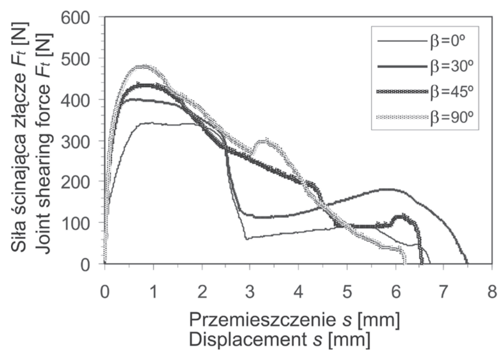

Fig. 9. The effect of layout angle β in relation to applied load direction on shearing force characteristics

The shearing force curve is a joint reaction to displacement that forces the joint element deformation. This reflects the order of joint lock degradation and energy demand until complete sheet separation.

If we know the shearing force characteristics (fig. 10) for considered layout angle, the work value may be determined by the following formula:

$$W = \int_{0}^{s_e} F_t(\beta) ds \quad (1)$$

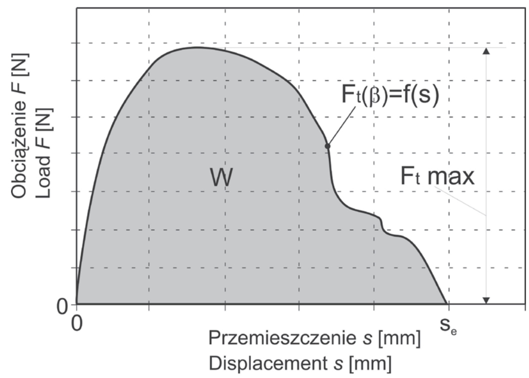

Fig. 10. The graphical interpretation of work made until joint separation

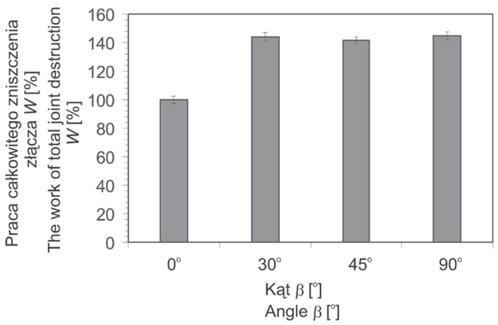

Fig. 11. Relation of joint destruction work and layout angle β

For tests with diametrically different joint layout angles in relation to applied load direction, the highest work value differences during the shearing test have been observed. The dissipation of an energy for complete sheet separation for $\beta = 90^o$ has been almost by 50% higher in relation to the shearing test for $\beta=0^o$ (fig. 11). For angles $\beta = 30^o$ and 45^o the work made had a value similar to the one for 90^o. The last two cases are accompanied by the mixed destruction mechanism, which was explained further in this paper.

For all cases, the complete joined sheet separation has occurred due to an overpress material decohesion. The separation method has depended on the shearing force components (fig. 12), which have been influenced by the joint layout angle.

The joined aluminum sheet strips have featured such a rigidity that generally all the applied load has been carried by the merging area during the test. Thus separated sheets for all specimens have not been deformed.

The individual shearing force curves along with the final appearance of specimens enable describing the joint separation mechanism.

When loading the joint for $\beta=0^o$ the separation has occurred due to a partial lock tear-up in area „1” along with an overpress material cohesion loss in areas „2” and „3” (fig. 13a). Basically, the longitudinal load of joint ($F_t=F_{t-w}$) has firstly resulted in bridge „I” stretching with force F^r_{t-w} and bridge „II” bending with torques M_{g1} i M_{g2} (fig. 14). The friction forces (T) have ac-

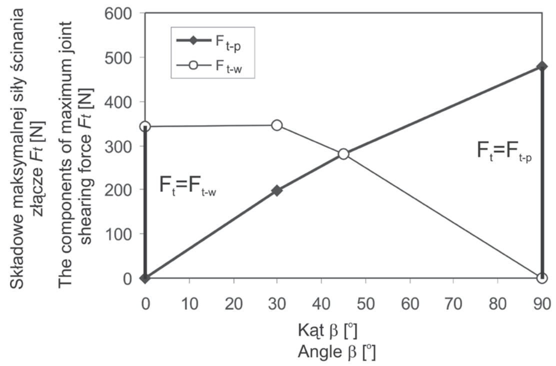

Fig. 12. The effect of layout angle β in relation to applied load direction on corresponding shearing force components

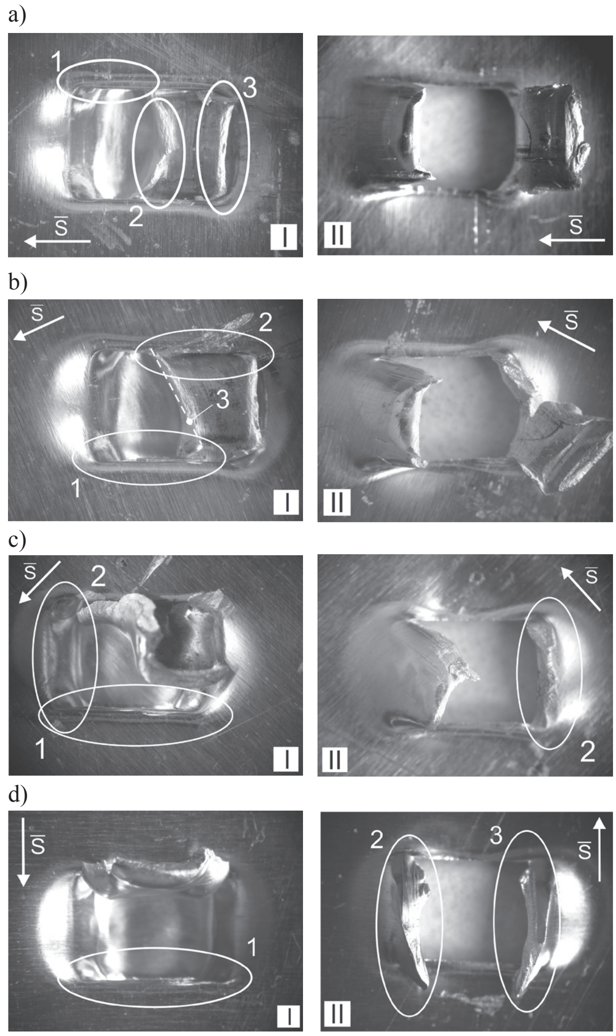

Fig. 13. The form of sheet merging area destruction achieved after the shearing test of rectangular clinching joint for layout angle β (I – lower sheet, II – upper sheet): a) 0^o, b) 30^o, c) 45^o, d) 90^o

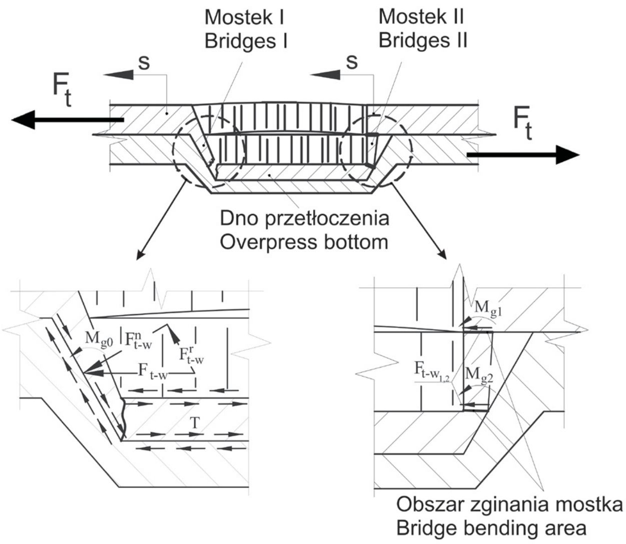

Fig. 14. Simplified description of joint bridge load during the shearing test for β=0°

companied the lock element displacement. For such a located joint during the strength test, the force firstly has risen, and then the force value has stabilized at 340 N (fig. 9). The further joint deformation has caused the bridge I breaking (area "3") and decreasing the shearing force to about 60 N. Then the gradual lock tear-up has been occurring in area "1" (fig. 13a) along with bridge II stretching. Since then the force has been increasing until the displacement of s≈6.75 mm (fig. 9), and the critical necking and bridge II material breaking (area "2" on fig. 13a).

In turn, lateral joint location (the line of cut material is perpendicular to an applied load direction) when shear testing (F_t=F_{t-p}) has resulted in a different force characteristics, comparing to the longitudinal location (fig. 9). The peak shearing force was 480 N and by 40% higher than for an angle of 0°.

When strength testing for β = 90° the joint has been destructed by lock tear-up in area „1" (fig. 13d), and bridge material cohesion loss in cross sections (areas "2" and "3" on fig. 13d). The application of shearing force F_t to joint has resulted in loading the overpress with resultant bending moment (M_{g1}) and shearing force (F_{t-p}). As a result the lock has been torn up in an overpress bottom area "b", and the bridge material cut off in cross section II_p (fig. 15).

The "I_p" cross section of joint has featured higher load-carrying ability than "II_p" cross section due to a larger area and lower strains during the joint forming. In the "a" area, the bottom material interference and its gradual rotation has been observed, thus the final position of an overpress bottom (fig. 13d). In the end of separation phase in the II_p cross section, only the shearing force and stretching force have accompanied the material cohesion loss.

When looking at the photos of destructed joints for intermediate β angle values (30°, 45°), it can be stated that the mixed destruction mechanism has occurred. When loading the joint for β=30°, firstly the lock tear-up has occurred in area "1" (fig. 13b). The slight loosing of seized material has accompanied the loading the sheet merging area, on the side of sheet cut in area "1". On the other hand, on the opposite side (in area "2") the gradual interference of joined layer material has occurred along with an increasing sheet displacement. Thus we have the layout

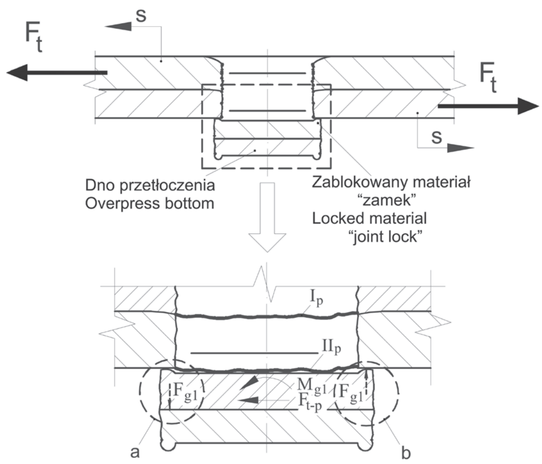

Fig. 15. Simplified description of joint load during the shearing test for β=90°

of an overpress material separation line (detail "3") with an angle of 90° in relation to sheet displacement.

Increasing the joint layout angle (β) in relation to displacement direction up to 45° has intensified the phenomena occurring just like for angle of 30°. As a result of the strength test, the turning out of the overpress bottom (fig. 13c) has accompanied the complete material tear-up in area "1". One of the bridges has been separated in the point of transition into the overpress bottom (area "2"). In previous cases the overpress bridges has been left along with the upper sheet.

5. Summary

Based on the presented experimental analysis we can state as follows:

- For a longitudinal joint load, the material cohesion loss firstly occurs in one bridge, and then all load is carried out by the rest of the lock created by pressing.

- The energy dissipation when destructing the sheet strips for β=90° has been by around 50% higher in relation to β=0° test case, but the maximum shearing force has been higher by about 40%.
- For all cases of joint layout, the diversified maximum shearing force has been achieved, and when considering the destruction work value, the similar value level has been achieved for three layout angles (30°, 45° and 90°).
- For lateral joint load, the important factor is creating possibly large material lock, which plays the significant role in joint rigidity.
- When designing the joint layout in the seam, the mounting easiness and its further operation in relation to load have to be considered.

The performed researches have revealed that such an experimental analysis might be a supplement and extension of the knowledge on rectangular clinching joint behavior for various load directions.

The specified merging area location may improve locally the load-carrying ability of single joints and balance the elastic effort of a sheet construction.

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