Analysis of the thermomechanical load impact on the riveted joint strength

Analiza wpływu obciążenia termomechanicznego na wytrzymałość połączenia z nitem zrywalnym

JACEK MUCHA
WALDEMAR WITKOWSKI *

DOI: https://doi.org/10.17814/mechanik.2017.2.35

Presented was the results of experimental analysis of single riveted joints strength. The joints shear strength was determined in temperature of 23, 400, 600, 800 Celsius degrees. The obtained results helped to explain how the temperature affects on the joint load characteristic. The experimental research was carried out for zinc coated S350GD sheet metal material.
KEYWORDS: riveted joint strength, thermomechanical load, S35GD+Z

In the recent period in the building construction industry, the use of lightweight structures made of cold rolled steel has considerably increased. The main advantages of lightweight cold-formed construction are low weight and assembly time, which is up to 30% shorter than for other steel structures [1].

The range of techniques for joining the thin-walled components is wide. Choosing the type of connection depends on a number of factors: material, strength and technology, as well as the type and purpose of the construction. The design process, including bonding nodes, should take into account the recommendations in EN 1993-1-8 [2].

Thin wall profiles are joined in a variety of ways, most commonly with rivet bolts [3-6], bolt (for composite structures) [1, 7, 8] or special tubular rivets [9-12]. Experimental analysis of joint strength of new joining systems of steel structure is presented in [13]. The results of double joints shear test (e.g. SPR, clinching) of 2 mm thick soft steel sheet S235JR were included.

New solutions do not always provide adequate strength. This is why classical riveting technologies with rivets for closing up or blind rivets are still used, especially in public utility buildings and residential homes where the connections must ensure dependability (fig. 1).

a) *b)*

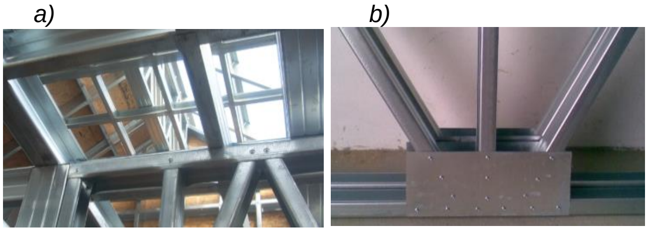


Fig. 1. Rigid connections in thin-walled cold-bent profiles: a) fragment of partition wall, b) node of four profiles

* Dr hab. inż. Jacek Mucha (j_mucha@prz.edu.pl), mgr inż. Waldemar Witkowski (wwitkowski@prz.edu.pl) – Katedra Konstrukcji Maszyn, Wydział Budowy Maszyn i Lotnictwa Politechniki Rzeszowskiej

Tubular rivet bolts belong to a large number of fasteners used in the assembly of thin-walled structures. Such connectors allow for highly efficient assembly. Rivets ensure to make durable, inseparable joints, but they require preparation of a pre-opening and proper positioning of the elements so that the joint can be positioned. The finished joint takes up relatively little space, its joining process is not complicated and requires only one side access to the joined components. The present solutions of riveted joints have quite diverse maximum load capacity - from several to several dozen or even several kN.They are so simple and interesting from the point of view of carrying capacity that research is being carried out on the possibility of joining without first making a hole [14, 15].

Scope, methodology and strength test

Rivet joints were made using a steel sheet of S350GD + Z275 (according to EN 10326 No. 1.0529) with a thickness of 1 ± 0.05 mm, hot-dip galvanized 275 g/m^2 with a thickness of ~ 20 µm. S350GD (1.0529) belonging to a group of structural steels with increased corrosion resistance due to the use of galvanic coating. Such steel is suitable, among others, for external structural elements exposed to atmospheric agents. Its basic mechanical properties are summarized in Table I, while chemical composition - in Table II.

TABLE I. Mechanical properties of S350GD material

$R_{p0.2}$, MPa	R_m, MPa	A_{80}, %	n	E, GPa
350	420	16	0,3	2,09

TABLE II. Chemical composition of S350GD material

Composition % – maximum values					
C	Mn	P	S	Si	Fe
0,20	1,50	0,10	0,04	0,6	rest

Connections with rivets were formed under equal conditions. However, it is difficult to maintain high reproducibility in blind rivet forming process because of the tubular part upsetting [16].The diameter of the steel rivet and the rivet hole was 5 mm. Five strength tests were performed at each temperature.

For riveting of the blind riveted joint with full mandrel at ambient temperature (23 °C), force stabilization within a specified range of displacement is observed (fig. 2 - s_1 to s_2).

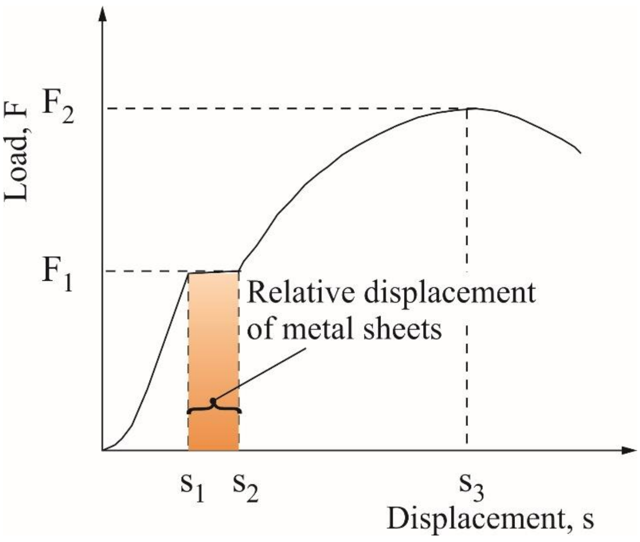


Fig. 2. Load transfer in riveted joint

In a typical riveted joint, the load is transmitted by the friction force (T) between the jointed sheet metal contacts:

$$T = \frac{\mu \sigma_r \pi d_n^2}{4} \quad (1)$$

where: μ - coefficient of friction, σ_r - tensile stress in the thread induced by the rolling process of the riveted rivet part, d_n - rivet diameter.

Constructors of thin-walled constructions often use the same tool for making holes for various rivets to simplify assembly technology. The clearance between the opening and the diameter of the rivet tubular part during loading of the joint causes the contact on the smaller surface (fig. 3). After exceeding the load equivalent to the frictional force, the force resulting from the load capacity of the surface is equal to:

$$F = \int_0^{\alpha} p \cdot cos\alpha \cdot t \cdot \frac{d_n}{2} d\alpha \quad (2)$$

where: p - permissible pressure, t - thickness of the joined element, angle α - circumferential angle of contact of the two cylindrical faces (sheet and rivet).

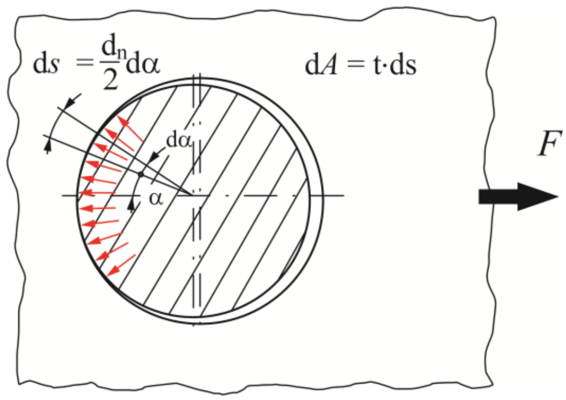


Fig. 3. Distribution of pressure on the sheet metal hole

The described load case occurs for a tubular rivet. The tubular material transfers the load in the fastener (fig.4), the mandrel blocked in the upset part presses the joined plates and blocks the joints. After exceeding the load capacity of the friction forces in the initial phase, loading stress concentrate along the surface of the rivet tubular part. As the tensile share testing machine holder movement increases, the rivet joint is rotated (detail in fig. 5*a*). Rivet intensively affects the surface of the sheet and deforms the material around the hole (fig.5b). In the overlap the sheets, in addition to stretching, are additionally bended, whereas the rivets are cut in one cross section.

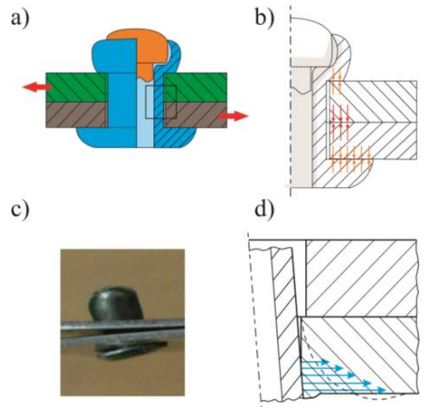


Fig. 4. Impact of rivet on sheet metal surface during shearing test

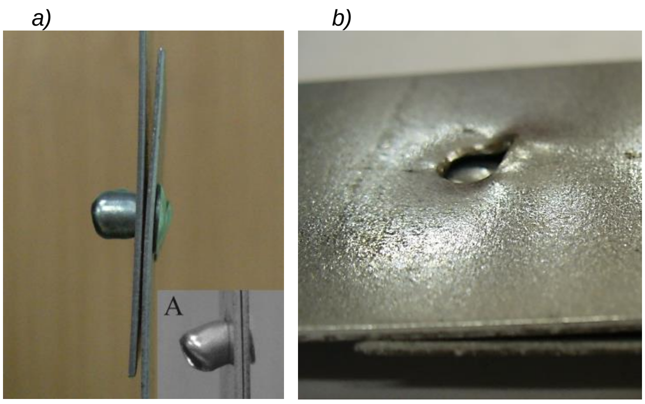


Fig. 5. Rivet joint shearing test (23 °C): *a)* rivet deformation, *b)* sheet metal deformation

For the shear characteristics of the joint at room temperature, the stop (load constant range) at 800 ÷ 900 N (fig. 6) is observed. The force oscillates near 850 N, while increasing the displacement of the beam of the strength machine. During the shear test in the forced displacement range from 0.65 mm to 2.05 mm, the clearance between the fastener and the plate hole was cleared and the head of the mandrel was moved. Further transfer of the load without deformation of the riveted tubular part is not possible. Increasing force is the result of overlapping mechanisms responsible for plastic deformation in the thread.

The maximum shear strength of the rivet joint reached 3160 N (fig. 6). Increasing the temperature load to 400 °C during the strength test changed the course of the coupling force. Oxidation of the zinc coating caused the metal sheets to lock against each other as a result of increased friction and the effect of sheet metal expandability. Transfer of the load over the connection immediately occurred. At a temperature of 400 °C, the maximum strength of the joint was reduced by 9% as compared to the shear joint at 23 °C. Further shear tests were about the same connection, but the temperature was 600 and 800 °C.

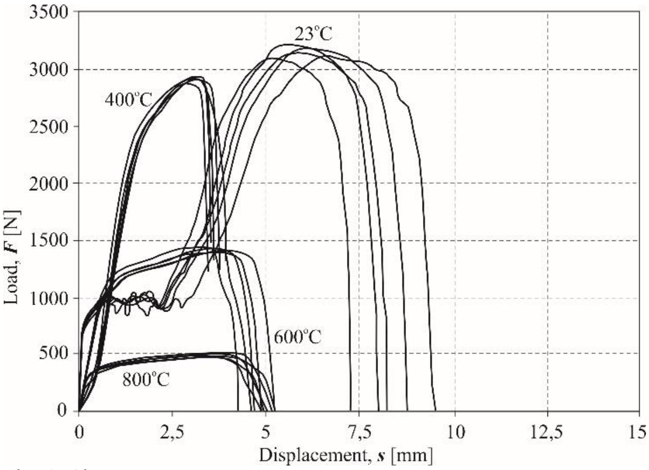


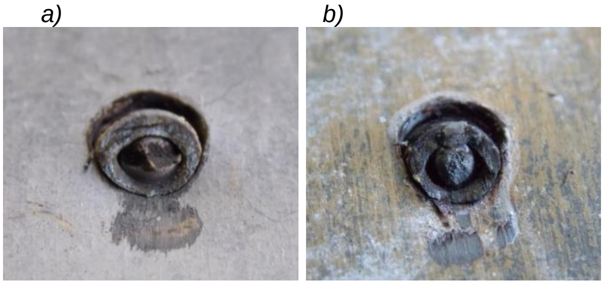
Fig. 6. Shear curves

As mentioned above, during the preheating of samples, the zinc coating on the plate surface was oxidized to the desired shear test temperature (fig. 7). As the load increased, the stress field moved to the outer edge of the plate openings. The higher the shearing test temperature, the more the effect was exacerbated. The blocked head of the core prevented the shearing of tubular portion in the plate contact plane. Loss of cohesion of the material of the rivet tubular part occurred at the end of the core (fig. 8).

a) *b*) *c*)

Fig. 7. Metal strips of the joint after shear test in a heated chamber at a temperature of: a) 400 °C, b) 600 °C, c) 800 °C

a) *b)*



c)

Fig. 8. Macrographic surface of rupture of the riveted tubular part. Shear test temperature of: *a)* 400 °C, *b)* 600 °C, *c)* 800 °C

Conclusions

The strength of the rivet joint drastically decreases with increasing temperature during the shearing test. The contact surfaces change as a result of faster plasticization of the material as the temperature rises. The higher the sample temperature, the smaller the discrepancy occurred in the course of the force curve.

As the temperature increased during the load test, the joint strength decreased and the difference between the maximum load and the load in the linear range decreased. The influence of temperature during the test significantly reduced the strength of the joint. The smallest difference in maximum strength occurred in the case of shear tests at 23 and 400 °C, and the highest at the temperature increase from 400 to 600 °C.

The work was co-organized by the Department of Machine Design of the Rzeszów University of Technology with Stalart Ltg. The authors thank the head of the Materials Research Laboratory for Aviation Industry Prof. Jan Sieniawski, Ph.D., Eng, for enabling the performance tests.

REFERENCES

1. Dano M.L., Gendron G., Picard A. “Stress and failure analysis of mechanically fastened joints in composite laminates”. *Compos. Struct*. 50 (2000): s. 287–296.

2. EN1993-1-8, Eurocode 3. Design of steel structures. Part1–8: Design of joints; 2005.

3. Mucha J., Witkowski W. “The experimental analysis of the double joint type change effect on the joint destruction process in uniaxial shearing test”. *Thin Wall. Struct*. 66 (2013): s. 39–49.

4. Bayan A., Sariffuddin S., Hanim O. “Cold formed steel joints and structures-a review”. *Int. J. Civil Struct. Eng*. 2, 2 (2011): s. 621–634.

5. Lu W., Mäkeläinen P., Outinen J., Ma Z. “Design of screwed steel sheeting connection a tambient and elevated temperatures”. *Thin Wall. Struct*. 49 (2011): s. 1526–1533.

6. Childs P. “Fastening and Power Screws”. *Mechanical Design Engineering Handbook*. Elsevier Ltd., 2014, s. 677–719.

7. Matsuzaki R., Shibata M., Todoroki A. “Improving performance of GFRP/aluminum single lap joints using bolted/co-cured hybrid method”. *Compos. Part A-Appl S*. 39 (2008): s. 154–163.

8. Kolesnikov B., Herbeck L., Fink A. “CFRP/titanium hybrid material for improving composite bolted joints”. *Compos. Struct*. 83 (2008): s. 368–380.

9. Moroni F., Pirondi A., Kleiner F. "Experimental analysis and comparison of the strength of simple and hybrid structural joints". *Int. J. Adhes. Adhes*. 30 (2010): s. 367–379.
10. Di Franco G., Fratini L., Pasta A. "Influence of the distance between rivets in self-piercing riveting bonded joints made of carbon fiber panels and AA2024 blanks". *Mater. Des*. 35 (2012): s. 342–349.
11. Di Franco G., Fratini L., Pasta A. "Analysis of the mechanical performance of hybrid (SPR/bonded) single-lap joints between CFRP panels and aluminum blanks". *Int. J. Adhes. Adhes*. 41 (2013): s. 24–32.
12. Masahito Ueda M., Miyake S., Hasegawa H., Hirano Y. "Instantaneous mechanical fastening of quasi-isotropic CFRP laminates by a self-piercing rivet". *Compos. Struct*. 94 (2012): s. 3388–3393.
13. Di Lorenzo G., Landolfo R. "Shear experimental response of new connecting systems for cold-formed structures". *Journal of Constructional Steel Research*. 60, 3–5 (2004): s. 561–579.
14. Mucha J., Witkowski W. Nit rurkowy do nitowania, zwłaszcza tarciowego. Zgłoszenie Patentowe UP RP: P.404729 (16.07.2013).
15. Min J., Li Y., Carlson B.E., Hu S.J., Li J., Lin J. "A new single-sided blind riveting method for joining dissimilar materials". *CIRP Annals – Manufacturing Technology*. 64, 1 (2015): 13–16.
16. Kelly B., Costello C. "FEA modelling of setting and mechanical testing of aluminum blind rivets". *J. Mater. Process. Technol.* 153–154 (2004): p 74–79. ■