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# EVALUATION OF THE RIVET HOLE SIZING DEGREE EFFECT ON THE FATIGUE LIFE

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***Abstract***

*This paper presents results of research on improvement of riveted joints fatigue life. That improvement was achieved using the rivet hole sizing process. The diagrams of sizing forces as the function of the hole sizing degree were analysed. Results of fatigue tests performed by the authors confirmed that the rivet hole sizing degree significantly influences fatigue life, and the improvement is proportional to the sizing degree.*

***Keywords:*** *riveted joints, fatigue life, rivet hole sizing*

## 1. Introduction

The fatigue strength of riveted joints is influenced by a number of design, process and material-related factors. Design factors include e.g. the type of the connection, size of the riveted joint, thickness of the connected metal plates, the rivet diameter and type or applied pitch of the joint [2]. Fatigue strength is also significantly influenced by rivet holes preparation process. This results from the fact that rivet holes are areas where local stress concentration occur. It is the place where fatigue cracks are initiated which may subsequently develop and lead to disasters.

Rivet holes may be subjected to special processing in order to increase their resistance to fatigue cracking. The most important processes of that kind include reaming and sizing. Reaming reduces the scatter of hole diameters and increases hole surface smoothness. While sizing introduces compressive stress to internal layers of the material. This stress hinders initiation of fatigue cracks on the hole surface. Holes may be sized using special burnishing heads. But this technology can only be used for sizing holes of 3 mm diameter and bigger. Such small holes can, however, be sized using mandrels of appropriate diameter. Achieved surface cold work degree depends on the difference between the diameter of the sized hole and the diameter of the sizing mandrel.

The aim of this study is to analyse the course of rivet hole sizing process using sizing mandrels and to evaluate the impact of the rivet hole sizing degree on the fatigue life. The research described in the study concerned improvement of the fatigue life of riveted joints as a result of local strain hardening of the rivet hole by the sizing process, which also results in the hole surface polishing.

## 2. Test samples

Samples for tests were made of 1.27 mm thick non-clad plates of aluminium grade 2024-T3. Rivet holes were prepared assuming that they shall be used for 3mm nominal diameter oval head solid rivets for aviation-related purposes [6]. According to [5], finished holes for such rivets should be of 3.1 mm diameter with positive tolerance of +0,1 mm. Holes of such diameter were achieved by two operations. The first one was drilling the hole and the second one – sizing the hole to the diameter of 3.1 mm. The research covered several degrees of hole sizing. In this study, the sizing degree $k$ means the following relationship:

$$k = \left( \frac{d_k - d_w}{d_w} \right) \cdot 100\% \,, \tag{1}$$

where:

$d_k$ – hole diameter after sizing,
$d_w$ – hole diameter after drilling.

Samples with holes made in conventional way (drilling or drilling and reaming) were also prepared for comparison purposes.

Different sizing degrees were achieved by drilling holes of different diameters in the samples followed by sizing process using sizing mandrel of the same diameter. Holes in the test samples were drilled using special device ensuring appropriate quality and repeatability of the holes. Figure 1a shows the profile of the test samples and the hole diameters. Based on preliminary tests it was concluded that 3.15 mm nominal diameter mandrel is necessary to size the holes to the diameter of 3.1 mm. The shape of the used sizing mandrel is shown in Figure 1b. Five different sizing degrees were achieved be means of five drills of different diameters for preliminary holes and one sizing mandrel. $k = 6.9\%$ ($d_w = 2.9$ mm), $k = 5.08\%$ ($d_w = 2.95$ mm), $k = 3.33\%$ ($d_w = 3.0$ mm), $k = 1.64\%$ ($d_w = 3.05$ mm), $k = 0.30\%$ ($d_w = 3.1$ mm).

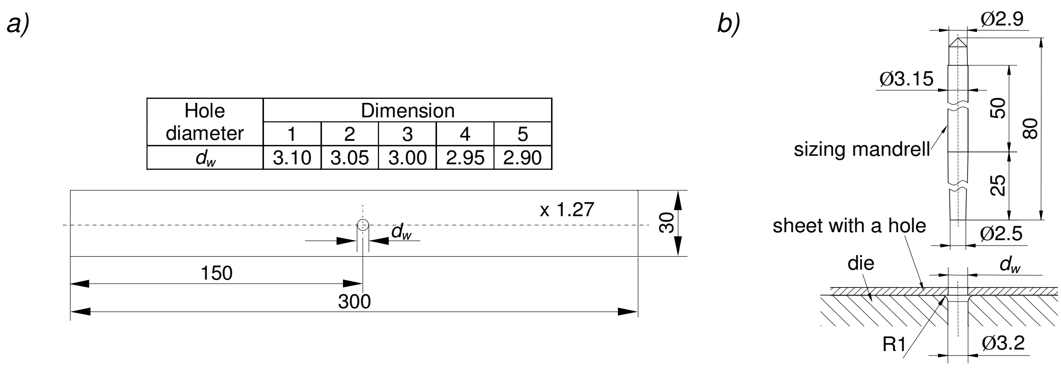


*Fig. 1. Samples for fatigue tests (a) and the sizing mandrel (b)*

## 3. Hole sizing tests

Holes were sized using the testing machine INSTRON 8501. To reduce sample deformation in its thickness direction during sizing process, the diameter of the hole in the die supporting the sample was (Ø3,2 mm) slightly bigger than the mandrel diameter (Ø3,15 mm). Momentary values of the force applied on the mandrel and the mandrel displacement in the hole were recorded during the sizing process.

Sample graph of 2.9 mm hole sizing force as a function of the mandrel displacement was shown in the figure 2. To better illustrate the hole sizing process, the sizing mandrel diagram with three characteristic sample positions with reference to the mandrel were provided under the graph. As expected, the loading force value depends on the position of the mandrel relative to the sample. The mandrel loading force increases linearly when the conical part of it mates with the hole and the force is maximum upon entry of the cylindrical part of the mandrel into the hole. The sizing force is decreasing during gradual displacement of the edge of the cylindrical part in the tapered hole and then, as expected, it remains approximately unchanged by the end of the sizing mandrel displacement.

Figure 2b shows mandrel loading force functions obtained when sizing the holes of different diameters. As the main process of the hole sizing takes place only in the initial stage of sizing (when forcing the tapered part of the mandrel into the hole), the diagrams focus only on that stage. As expected, maximum values of the force applied to the mandrel were observed when forcing the mandrel through the holes drilled using the smallest drill ($d_w$=2.9 mm, $k$=6.9%). Moreover, based on the achieved graphs, one can also find that they are qualitatively similar. This applies to the shape of prepared sizing mandrel load graphs in their section regarding the tapered part of the mandrel.

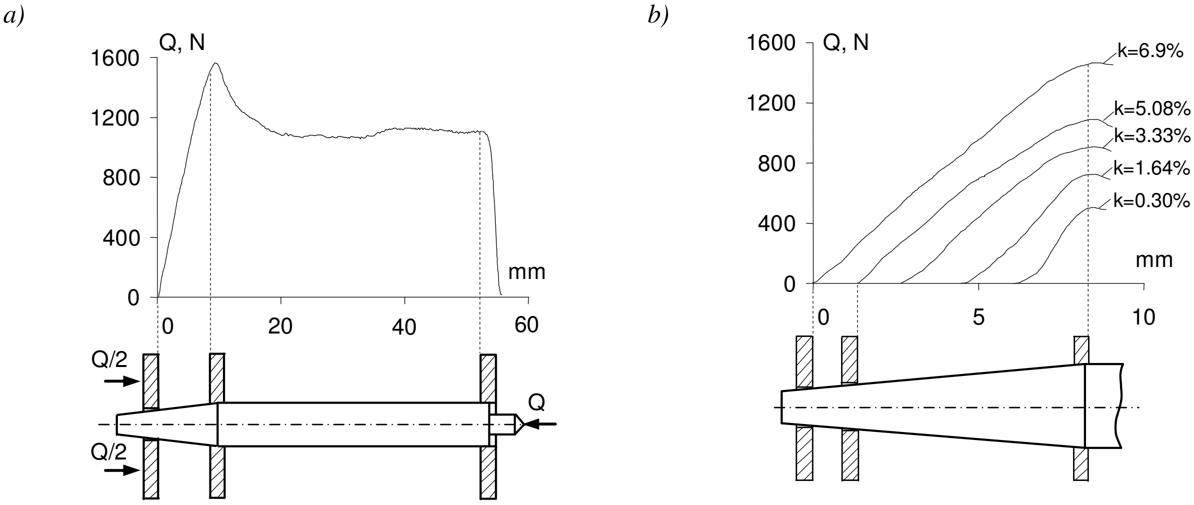


*Fig. 2. Hole sizing: a) function of the force for 2.9 mm hole sizing process, b) force functions for sizing holes of different diameters*

Hole diameters were measured after sizing. The measurement results were presented in form of a graph (Fig. 3), where hole diameters measured after drilling were additionally presented. Based on the prepared graphs, it can be noted that the machining-related deviation of the diameter depends on the diameter of the hole. The bigger the drill diameter, the smaller the deviation. One can conclude, that despite additional drill guide used during hole drilling, the holes are enlarged due to radial run-out.

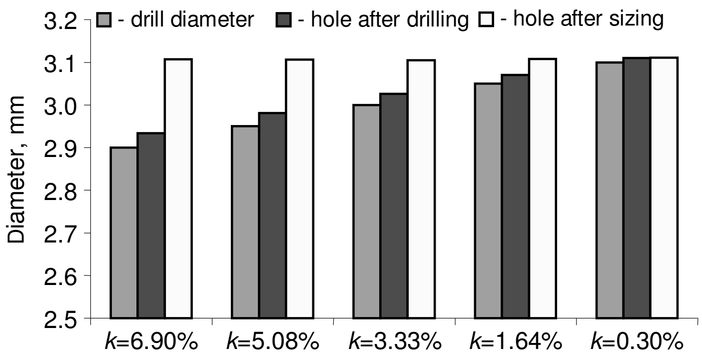


*Fig. 3. The results of diameter measurement of holes in samples, acquired after drilling and after sizing*

Apart from experimental tests, the sizing process simulation was also performed with finite element method (FEM) using ABAQUS software, version 6.6-4 - Standard module [1]. Dimensions of the sizing mandrel used for experimental test and the simulation as well as dimensions of the sized hole made in the metal plate and die dimensions were shown in the Figure 1b. Due to the type of the system geometry, axially symmetrical 2D model was used for calculations. Both the sizing mandrel and the die were modelled as rigid elements, while the drilled metal plate as a deformable element for which non-linear material characteristics was assumed, achieved by discretization of the monotonous tension graph. As large deformation gradients were expected, the metal plate was discretized using axially symmetrical, 8-node, quadrangle finite element CAX8R. The number of elements was increased around the hole.

Figure 4 shows numerically determined, sample graph of the force necessary to size 3.03 mm hole from a hole drilled with 3.0 mm drill (sizing degree $k = 3.33\%$) as a function of the mandrel displacement. Performed simulations of the process for different values of the friction between the sizing mandrel and the hole indicate that it is one of the major factors influencing the hole sizing force, which does not, however, change, the nature of the process. Properly selected value of the friction factor in the digital model allowed to achieve high compliance with the results of experimental tests of the sizing force as well as the maximum hole sizing force.

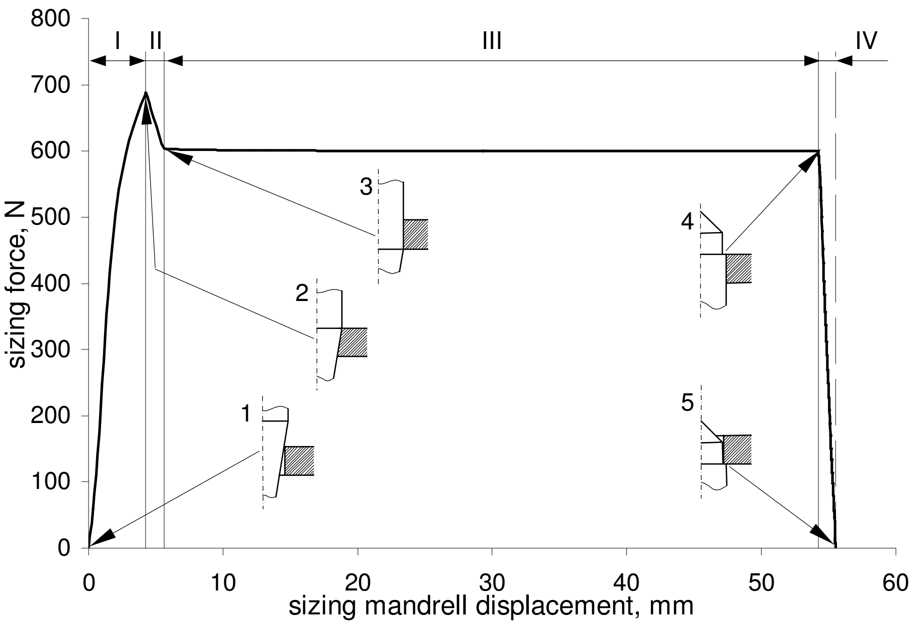


*Fig 4. The graph of the hole sizing force as a function of the sizing mandrel displacement, determined using FEM*

Several characteristic stages can be distinguished in the sizing force graph, based on the FEM analysis. Stage I starts with contact between the sizing mandrel and the top edge of the hole and ends when the cylindrical part of the sizing mandrel is aligned with that edge. The sizing force is maximum at that moment. The force starts to decrease gradually from that moment (stage II) by the time, when the tapered part of the mandrel completely leaves the hole. At stage III, when the cylindrical part of the mandrel is forced through the hole, the sizing force virtually does not change. Stage IV begins when the end of the cylindrical part of the sizing mandrel is aligned with the top edge of the hole. The sizing force starts to decrease gradually from that moment down to zero, at which time the cylindrical part of the mandrel is totally outside the hole.

Almost the entire course of the sizing force at the stage III indicates that it is possible to significantly reduce the cylindrical part of the mandrel, which should shorten the process duration.

Results of numerical calculations indicate that maximum radial and axial deformations occur at the hole edge from the sizing mandrel entry side – at the initial stage of the sizing process (stage I), the tapered part of the mandrel is in point contact with the hole edge, which result in high gradient of stress in that area. This has significantly lower effect on the distribution of the circumferential deformations. Relief (stage IV - point 5) has little effect on the character of strain distribution in the hole area. While there are important differences in stress distribution. Load relief practically eliminates radial compressive stress resulting from sizing process. Whereas sizing process introduces high circumferential compressive stress in the material.

## 4. Fatigue tests

The samples with holes of different sizing degree were subject to fatigue tests. The tests were performed under zero-tension cycle conditions (cycle asymmetry factor $R$=0) with load frequency of 5 Hz. The tests were performed for three levels of the maximum load of the cycle $S_{max}$ = 150, 175 and 200 MPa (three samples for each load level). Like sizing of the holes, fatigue tests were also performed using the testing machine INSTRON 8501.

Results obtained during fatigue tests were presented in Figure 5 in bilogatithmic coordinate system, in form of fatigue graphs determined assuming $S_{max}$ as the independent variable of the stress and the fatigue life $N$ as the dependant variable. Results of the fatigue life tests acquired for drilled holes (W) as well as drilled and reamed holes (R) were also added in the figure for comparison. Figure 6 includes the summary of average fatigue life ratio of samples with sized holes to samples with drilled holes, presented for individual load levels.

Based on the achieved results, one can conclude that the lowest fatigue life characterised samples with drilled holes and drilled and reamed holes. The fatigue life of riveted joints improved (by 50 to 74%, depending on load level) even as a result of the hole surface polishing only. This improvement was obtained for samples with $d_w$=3.1 mm ($k$=0.30%) holes. While two-fold growth of the fatigue life was achieved for $d_w$=3.05 mm hole with slight sizing degree of $k$=1.64%.

Further significant increase of the fatigue life was achived by cold work of the hole surface and, based on the position of obtained fatigue life graphs (Fig. 5) and achieved fatigue life values (Fig. 6), it may be concluded that the higher the sizing degree, the higher the fatigue life growth. The growth is also proportional to the mandrel load level. For example, five-fold fatigue life increase (for the load level of 200 MPa) and eight-fold increase (for the load level of 150 MPa) were achieved for samples with $d_w$=3.0 mm ($k$=3.33%) sized holes. Maximum improvement of fatigue life was obtained for samples with $d_w$=2.9 mm ($k$=6.90%) sized holes, but the results were characterised by the highest dispersion. Nine-fold improvement of fatigue life was achieved for those samples comparing with drilled hole for the load level of $S_{max}$ = 200 MPa and nearly twelve-fold increase for the load level of $S_{max}$ = 150 MPa.

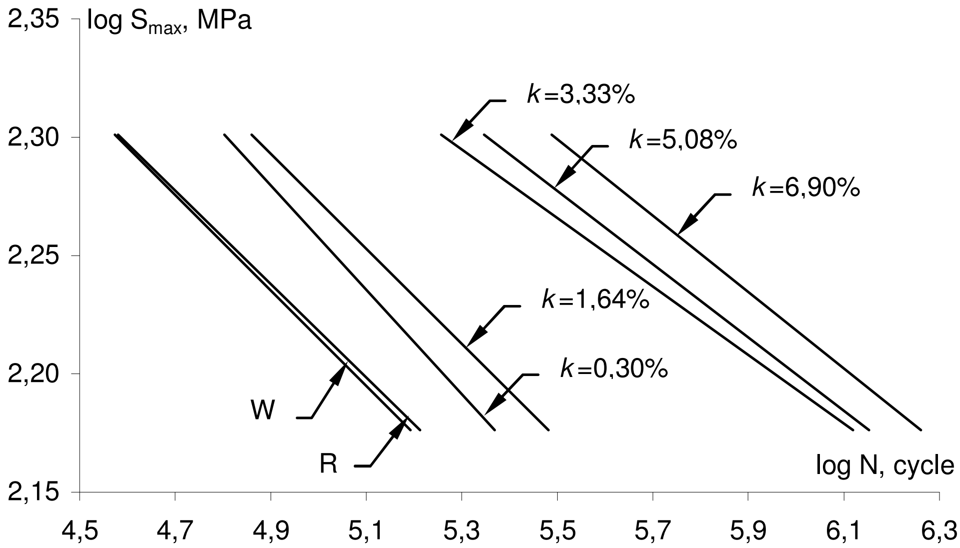


*Fig. 5. Fatigue life graphs obtained for samples with holes of different sizing degree*

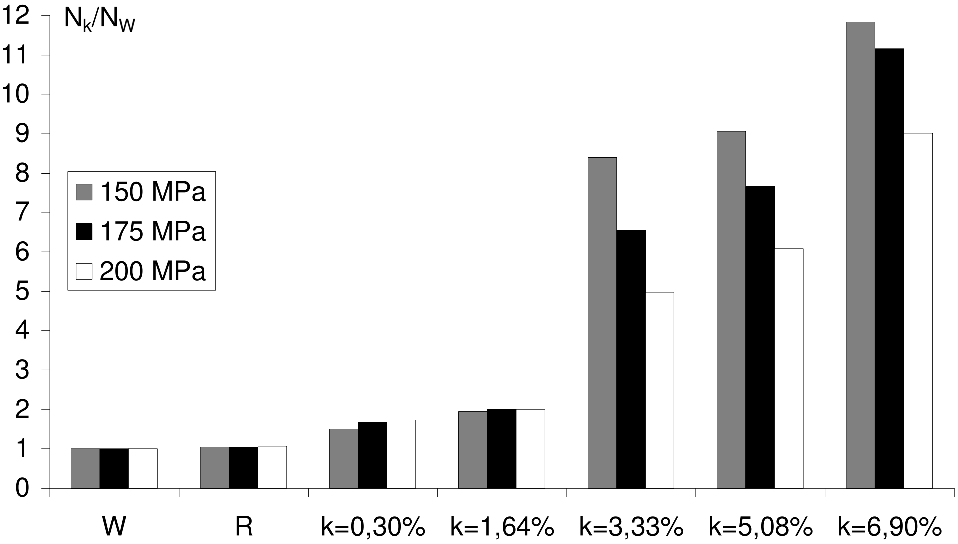


*Fig. 6. Average fatigue life ratio of samples with sized holes $N_k$ to samples with drilled holes $N_W$*

## 5. Summary

Fatigue life of riveted joints improves thanks to additional preparatory operations performed prior to riveting, such as hole sizing. Results obtained in this research confirm information available in the professional literature, concerning positive effect of hole sizing on fatigue life [3]. Cold work and polishing of the hole surface by the sizing mandrel hinders initiation of micro-cracks. It should be emphasized that a number of factors influence fatigue life of the sample with riveted hole. The most important of them include the rivet upset (squeezing) degree or the clearance between the rivet and the hole [4]. Those issues are subject of research works performed in the Institute Laboratory for Research on Materials and Structures of the Faculty of Mechanical Engineering at the University of Technology and Life Sciences in Bydgoszcz, as part of the Eureka IMPERJA project. Those works have, among other things, proven positive effect of hole sizing on fatigue life of riveted pairs used in aviation industry structures.

## References


[1] ABAQUS Version 6.6 PDF Documentation. ABAQUS Inc., 2006.

[2] Jachimowicz J., Szymczyk E., Sławiński G., *Analiza wpływu technologii nitowania na stan przemieszczeń, odkształceń i naprężeń wokół nitu*, Mechanik Nr 4/2008, ss. 332-337.

[3] Larouche S. at all, *Influence of Cold Working and Interference Fit on Fatigue Life of 7475-T7351 Aluminum Alloy Fastener Hole*, Design for Durability in the 21th Symposium of the International Committee on Aeronautical Fatigue, 27-29 June 2001, Toulouse, France, Ed. J. Rouchon Cepadues, pp. 681-698.

[4] Szymczyk E., Jachimowicz J., Sławiński G., *Analiza wpływu luzów technologicznych na pole naprężeń własnych w otoczeniu nitu stożkowego*, Mechanik Nr 7/2008, ss. 629-632.

[5] Norma branżowa BN-70/1120-03 *Nity lotnicze. Dobór długości, wymiary zakuwek i średnice otworów na nity*.

[6] Norma branżowa BN-70/1121-03 *Nity lotnicze ze łbem kulistym*.



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