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EVALUATION OF THE SELECTED FACTORS EFFECT ON THE FATIGUE LIFE OF SPECIMENS WITH SIZED AND RIVETED HOLE PART I. DESIGN OF EXPERIMENT AND TESTS RESULTS

Adam Lipski

University of Technology and Life Sciences in Bydgoszcz
Faculty of Mechanical Engineering
Al. Prof. S. Kaliskiego 7, 85-789 Bydgoszcz, Poland
tel.: +48 52 3408220, fax: +48 52 3408271
e-mail: adam.lipski@utp.edu.pl

Abstract

Evaluation of the fatigue load, the rivet squeezing force, the velocity of rivet close up and the hole diameter before sizing (after drilling) effect on the fatigue life of specimens with sized and riveted hole was presented in this paper. The work contains two parts. Design of experiment and the results of the fatigue tests performed by the described experiment plan was presented in the first part. The statistical analyses and examples of using the mathematical model of the experimental unit were presented in the second part.

Keywords: *riveted joints, fatigue life, rivet hole sizing, design of experiment*

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 [1]. 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 (for holes of 3 mm diameter and bigger) or small holes can 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. Those problems were analysed in paper [5].

The fatigue strength of sized rivet holes is influenced by a number of factors. The experimental analysis of those factors from fatigue point of view is very long-lasting and expensive. Efficiency and informative are very significant in this type of experiments. Experimental design methods are particularly useful in this case.

The example of evaluation of the selected factors effect on the fatigue crack initiation in the area of sized rivet hole by using experimental design was presented in this paper. The analysis was performed by using results obtained from the experiment plan developed on the basis of [2-4,6]. Specimens for tests were made of 1.27 mm thick non-clad plates of aluminium grade 2024-T3 [5] with sized hole riveted by using snap head rivet for aircraft with 3 mm diameter and 5 mm length compatible with Polish Standard BN-70/1121-03 (3517A-3-6). Rivets were made of aluminium grade PA24.

2. Experimental design

2.1. Classification of quantity describing the experimental unit

2.1.1. Independent (input) variables

A set of the independent variables was assumed on the base of preliminary tests described in [5]:

x_1 - a nominal fatigue load in a hole section described by maximal tension stress in a cycle (the cycle asymmetry factor R=0) S_{max}, MPa,

x_2 - a rivet squeezing force P, kN,

x_3 - a velocity of rivet close up v, mm/s,

x_4 - a hole diameter before sizing (after drilling) d_w, mm.

2.1.2. Control variables

A set of control variables was assumed:

c_1 - a rivet diameter d_n = 3.0 mm,

c_2 - a sheet thickness g = 1.27 mm,

c_3 - type of the rivet – snap head rivet for aircraft [7],

c_4 - a rivet lenght l_n = 5 mm,

c_5 - a load frequency f = 10 Hz,

c_6 - drilling and sizing process conditions,

c_7 - sheet and rivet material.

2.1.3. Disturbing variables

As the basic disturbing variables were assumed:

z_1 - hole drilling and sizing inaccuracy,

z_2 - rivet dimensions inaccuracy.

2.1.4. Dependent (output) variable

Fatigue life (number of the constant amplitude cycles to the failure) was assumed as the dependent variable:

y - the common logarithm of the fatigue life N_c, cycle:

$$y = \log N_c \, . \tag{1}$$

The dependent variable in logarithmic form was assumed by analogy to Wöhler’s equation in semi-logarithmic scale. The dependent variable without logarithmic form was also previously analysed but statistical analyses demonstrated no adequacy of this mathematical model.

2.2. Ranges of independent variables

The minimum and maximum value were assumed for particular independent variables:

– for the maximum tension stress in a cycle (R=0) S_{max}:

$$x_{1\,min} = 150 \text{ MPa}, \tag{2}$$

$$x_{1\,max} = 250 \text{ MPa}, \tag{3}$$

– for the rivet squeezing force P:

$$x_{2\,min} = 8.5 \text{ kN}, \tag{4}$$

$$x_{2\,max} = 12.9 \text{ kN}, \tag{5}$$

– for the velocity of rivet close up v:

$$x_{3\,min} = 0.02 \text{ mm/s}, \tag{6}$$

$$x_{3\,max} = 0.14 \text{ mm/s}, \tag{7}$$

– for the hole diameter before sizing d_w:

$$x_{4\,min} = 2.9 \text{ mm}, \tag{8}$$

$$x_{4\,max} = 3.1 \text{ mm}. \tag{9}$$

2.3. Mathematical model of the experimental unit

It was assumed in this work that the relationship between fatigue life and riveting process factors and fatigue load can be described by the equation in the form of the second-degree polynomial with dual interactions:

– in the sum form:

$$\hat{y} = b_0 + \sum_{i=1}^{n} b_i \cdot x_i + \sum_{i=1}^{n} b_{ii} \cdot x_i^2 + \sum_{i=1,\, j=1,\, i<j}^{n} b_{ij} \cdot x_i \cdot x_j \,, \tag{10}$$

– in the expanded form:

$$\begin{aligned} \hat{y} = {} & b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + b_4 \cdot x_4 + \\ & + b_{11} \cdot x_1^2 + b_{22} \cdot x_2^2 + b_{33} \cdot x_3^2 + b_{44} \cdot x_4^2 + \\ & + b_{12} \cdot x_1 \cdot x_2 + b_{13} \cdot x_1 \cdot x_3 + b_{14} \cdot x_1 \cdot x_4 + \\ & + b_{23} \cdot x_2 \cdot x_3 + b_{24} \cdot x_2 \cdot x_4 + \\ & + b_{34} \cdot x_3 \cdot x_4. \end{aligned} \tag{11}$$

The assumed mathematical model of the experimental unit has 15 unknown coefficients of equation (11).

2.4. Independent variables coding

It was assumed five values for each independent variable.

The independent variables were coded by using the following equations:

a) centre points of the independence variables:

$$x_{i0} = \frac{x_{i\max} + x_{i\min}}{2}, \quad \text{for } i = 1, 2, ..., n, \tag{12}$$

hence:

$$x_{10} = \frac{x_{1\max} + x_{1\min}}{2} = \frac{250 + 150}{2} = 200 \text{ MPa}, \tag{13}$$

$$x_{20} = \frac{x_{2\max} + x_{2\min}}{2} = \frac{12.9 + 8.5}{2} = 10.7 \text{ kN}, \tag{14}$$

$$x_{30} = \frac{x_{3\max} + x_{3\min}}{2} = \frac{0.14 + 0.02}{2} = 0.08 \text{ mm/s}, \tag{15}$$

$$x_{40} = \frac{x_{4\max} + x_{4\min}}{2} = \frac{3.1 + 2.9}{2} = 3.0 \text{ mm}, \tag{16}$$

b) an axial point:

$$\alpha = \sqrt[4]{2^n} = \sqrt[4]{2^4} = 2, \tag{17}$$

c) variability units of independence variables:

$$\Delta x_i = \frac{x_{i\max} + x_{i0}}{\alpha}, \quad \text{for } i = 1, 2, ..., n, \tag{18}$$

hence:

$$\Delta x_1 = \frac{x_{1\max} - x_{10}}{2} = \frac{250 - 200}{2} = 25 \text{ MPa}, \tag{19}$$

$$\Delta x_2 = \frac{x_{2\max} - x_{20}}{\alpha} = \frac{12.9 - 10.7}{2} = 1.1 \text{ kN}, \tag{20}$$

$$\Delta x_3 = \frac{x_{3\max} - x_{30}}{\alpha} = \frac{0.14 - 0.08}{2} = 0.03 \text{ mm/s}, \tag{21}$$

$$\Delta x_4 = \frac{x_{4\max} - x_{40}}{\alpha} = \frac{3.1 - 3.0}{2} = 0.05 \text{ mm}, \tag{22}$$

d) coding and decoding relations:
- a coding relation:

$$\breve{x}_i = \frac{x_i - x_{i0}}{\Delta x_i}, \quad \text{for } i = 1, 2, ..., n, \tag{23}$$

- a decoding relation:

$$x_i = x_{i0} + \breve{x}_i \cdot \Delta x_i, \quad \text{for } i = 1, 2, ..., n, \tag{24}$$

e) real values corresponding to coded values of independent variables:
- for $\breve{x}_i = -\alpha$:

$$x_{1(-\alpha)} = x_{10} + \breve{x}_1 \cdot \Delta x_1 = 200 - 2 \cdot 25 = 150 \text{ MPa}, \tag{25}$$

$$x_{2(-\alpha)} = x_{20} + \breve{x}_2 \cdot \Delta x_2 = 10.7 - 2 \cdot 1.1 = 8.5 \text{ kN}, \tag{26}$$

$$x_{3(-\alpha)} = x_{30} + \breve{x}_3 \cdot \Delta x_3 = 0.08 - 2 \cdot 0.03 = 0.02 \text{ mm/s}, \tag{27}$$

$$x_{4(-\alpha)} = x_{40} + \breve{x}_4 \cdot \Delta x_4 = 3.0 - 2 \cdot 0.05 = 2.9 \text{ mm}, \tag{28}$$

– for $\breve{x}_i = -1$:

$$x_{1(-1)} = x_{10} + \breve{x}_1 \cdot \Delta x_1 = 200 - 1 \cdot 25 = 175 \text{ MPa}, \tag{29}$$

$$x_{2(-1)} = x_{20} + \breve{x}_2 \cdot \Delta x_2 = 10.7 - 1 \cdot 1.1 = 9.6 \text{ kN}, \tag{30}$$

$$x_{3(-1)} = x_{30} + \breve{x}_3 \cdot \Delta x_3 = 0.08 - 1 \cdot 0.03 = 0.05 \text{ mm/s}, \tag{31}$$

$$x_{4(-1)} = x_{40} + \breve{x}_4 \cdot \Delta x_4 = 3.0 - 1 \cdot 0.05 = 2.95 \text{ mm}, \tag{32}$$

– for $\breve{x}_i = 0$:

$$x_{1(0)} = x_{10} + \breve{x}_1 \cdot \Delta x_1 = 200 \text{ MPa}, \tag{33}$$

$$x_{2(0)} = x_{20} + \breve{x}_2 \cdot \Delta x_2 = 10.7 \text{ kN}, \tag{34}$$

$$x_{3(0)} = x_{30} + \breve{x}_3 \cdot \Delta x_4 = 0.08 \text{ mm/s}, \tag{35}$$

$$x_{4(0)} = x_{40} + \breve{x}_4 \cdot \Delta x_4 = 3.0 \text{ mm}, \tag{36}$$

– for $\breve{x}_i = +1$:

$$x_{1(+1)} = x_{10} + \breve{x}_1 \cdot \Delta x_1 = 200 + 1 \cdot 25 = 225 \text{ MPa}, \tag{37}$$

$$x_{2(1)} = x_{20} + \breve{x}_2 \cdot \Delta x_2 = 10.7 + 1 \cdot 1.1 = 11.8 \text{ kN}, \tag{38}$$

$$x_{3(+1)} = x_{30} + \breve{x}_3 \cdot \Delta x_3 = 0.08 + 1 \cdot 0.03 = 0.11 \text{ mm/s}, \tag{39}$$

$$x_{4(+1)} = x_{40} + \breve{x}_4 \cdot \Delta x_4 = 3.0 + 1 \cdot 0.05 = 3.05 \text{ mm}, \tag{40}$$

– for $\breve{x}_i = +\alpha$:

$$x_{1(+\alpha)} = x_{10} + \breve{x}_1 \cdot \Delta x_1 = 200 + 2 \cdot 25 = 250 \text{ MPa}, \tag{41}$$

$$x_{2(+\alpha)} = x_{20} + \breve{x}_2 \cdot \Delta x_2 = 10.7 + 2 \cdot 1.1 = 12.9 \text{ kN}, \tag{42}$$

$$x_{3(+\alpha)} = x_{30} + \breve{x}_3 \cdot \Delta x_3 = 0.08 + 2 \cdot 0.03 = 0.14 \text{ mm/s}, \tag{43}$$

$$x_{4(+\alpha)} = x_{40} + \breve{x}_4 \cdot \Delta x_4 = 3.0 + 2 \cdot 0.05 = 3.1 \text{ mm}, \tag{44}$$

f) summary of real and coded values of independence variables (tab. 1)

Tab. 1. Summary of values of independence variables for the assumed plan of experiment

Parameter level	Real values				Coded values			
	x_1	x_2	x_3	x_4	$\breve{x}_1$	$\breve{x}_2$	$\breve{x}_3$	$\breve{x}_4$
	MPa	kN	mm/s	mm	-	-	-	-
axial lower point	150	8.5	0.02	2.90	$-\alpha$	$-\alpha$	$-\alpha$	$-\alpha$
lower point	175	9.6	0.05	2.95	-1	-1	-1	-1
central point	200	10.7	0.08	3.00	0	0	0	0
upper point	225	11.8	0.11	3.05	+1	+1	+1	+1
axial upper point	250	12.9	0.14	3.10	$+\alpha$	$+\alpha$	$+\alpha$	$+\alpha$

g) the mathematical model of the experimental unit in the expanded coded form:

$$\begin{aligned}\hat{y} = {} & k_0 + k_1 \cdot \breve{x}_1 + k_2 \cdot \breve{x}_2 + k_3 \cdot \breve{x}_3 + k_4 \cdot \breve{x}_4 + \\ & + k_{11} \cdot \breve{x}_1^2 + k_{22} \cdot \breve{x}_2^2 + k_{33} \cdot \breve{x}_3^2 + k_{44} \cdot \breve{x}_4^2 + \\ & + k_{12} \cdot \breve{x}_1 \cdot \breve{x}_2 + k_{13} \cdot \breve{x}_1 \cdot \breve{x}_3 + k_{14} \cdot \breve{x}_1 \cdot \breve{x}_4 + \\ & + k_{23} \cdot \breve{x}_2 \cdot \breve{x}_3 + k_{24} \cdot \breve{x}_2 \cdot \breve{x}_4 + \\ & + k_{34} \cdot \breve{x}_3 \cdot \breve{x}_4 ,\end{aligned} \tag{45}$$

where:

$$\begin{aligned}k_0 = {} & b_0 + \sum_{i=1}^{4} b_i \cdot x_{i0} + \sum_{i=1}^{4} b_{ii} \cdot x_{i0}^2 + \sum_{i=1, i<j}^{4} b_{ij} \cdot x_{i0} \cdot x_{j0} = \\ = {} & b_0 + b_1 \cdot x_{10} + b_2 \cdot x_{20} + b_3 \cdot x_{30} + b_4 \cdot x_{40} + \\ & + b_{11} \cdot x_{10}^2 + b_{22} \cdot x_{20}^2 + b_{33} \cdot x_{30}^2 + b_{44} \cdot x_{40}^2 + \\ & + b_{12} \cdot x_{10} \cdot x_{20} + b_{13} \cdot x_{10} \cdot x_{30} + b_{14} \cdot x_{10} \cdot x_{40} + \\ & + b_{23} \cdot x_{20} \cdot x_{30} + b_{24} \cdot x_{20} \cdot x_{40} + \\ & + b_{34} \cdot x_{30} \cdot x_{40} ,\end{aligned} \tag{46}$$

$$\begin{aligned}k_1 = {} & b_1 \cdot \Delta x_1 + b_{12} \cdot x_{20} \cdot \Delta x_1 + b_{13} \cdot x_{30} \cdot \Delta x_1 + b_{14} \cdot x_{40} \cdot \Delta x_1 + \\ & + 2 \cdot b_{11} \cdot x_{10} \cdot \Delta x_1 ,\end{aligned} \tag{47}$$

$$\begin{aligned}k_2 = {} & b_2 \cdot \Delta x_2 + b_{12} \cdot x_{10} \cdot \Delta x_2 + b_{23} \cdot x_{30} \cdot \Delta x_2 + b_{24} \cdot x_{40} \cdot \Delta x_2 + \\ & + 2 \cdot b_{22} \cdot x_{20} \cdot \Delta x_2 ,\end{aligned} \tag{48}$$

$$\begin{aligned}k_3 = {} & b_3 \cdot \Delta x_3 + b_{13} \cdot x_{10} \cdot \Delta x_3 + b_{23} \cdot x_{20} \cdot \Delta x_3 + b_{34} \cdot x_{40} \cdot \Delta x_3 + \\ & + 2 \cdot b_{33} \cdot x_{30} \cdot \Delta x_3 ,\end{aligned} \tag{49}$$

$$\begin{aligned}k_4 = {} & b_4 \cdot \Delta x_4 + b_{14} \cdot x_{10} \cdot \Delta x_4 + b_{24} \cdot x_{20} \cdot \Delta x_4 + b_{34} \cdot x_{30} \cdot \Delta x_4 + \\ & + 2 \cdot b_{44} \cdot x_{40} \cdot \Delta x_4 ,\end{aligned} \tag{50}$$

$$k_{12} = b_{12} \cdot \Delta x_1 \cdot \Delta x_2 , \tag{51}$$

$$k_{13} = b_{13} \cdot \Delta x_1 \cdot \Delta x_3 , \tag{52}$$

$$k_{14} = b_{14} \cdot \Delta x_1 \cdot \Delta x_4 , \tag{53}$$

$$k_{23} = b_{23} \cdot \Delta x_2 \cdot \Delta x_3 , \tag{54}$$

$$k_{24} = b_{24} \cdot \Delta x_2 \cdot \Delta x_4 , \tag{55}$$

$$k_{34} = b_{34} \cdot \Delta x_3 \cdot \Delta x_4 \,, \tag{56}$$

$$k_{11} = b_{11} \cdot \Delta x_1^2 \,, \tag{57}$$

$$k_{22} = b_{22} \cdot \Delta x_2^2 \,, \tag{58}$$

$$k_{33} = b_{33} \cdot \Delta x_3^2 \,, \tag{59}$$

$$k_{44} = b_{44} \cdot \Delta x_4^2 \,. \tag{60}$$

2.5. Plan of the experiment

The fatigue tests were made in agreement with the static determined five level ($-\alpha$, -1, 0, +1, $+\alpha$) plan of the experiment PS/DS-P:λ (in Polish classification) [2-4,6]. The static determined full factorial plan PS/DK-2^n was the base for this plan.

Required number of independent variables sets:

$$N = n_k + n_\alpha + n_0 = 2^n + 2 \cdot n + n_0 = 2^4 + 2 \cdot 4 + 7 = 31, \tag{61}$$

where:

$n_k = 2^n$ – a number of sets for full factorial plan PS/DK-2^n,
$n_\alpha = 2 \cdot n$ – a number of sets for axial points,
$n_0 = 7$ – a number of sets for central points (for $n = 4$).

Summary of sets for the experiment was presented in tab. 2.

The plan of experiment has $N = 31$ sets. The minimum number of repetition of each set was assumed as $r = 3$. Hence, the total number of fatigue tests for assumed plan of experiment is

$$N_r = N \cdot r = 93 \,. \tag{62}$$

The presented plan of experiment make possible analysis of non-linear response surface of the experimental unit (characteristic for fatigue) and thanks to this it has high informativeness close to the static determined full factorial plan PS/DK.

Moreover the advantage of this plan is the high efficiency factor described by relation

$$e_N = \frac{N}{N_k} = \frac{31}{625} = 0.0496 \,, \tag{63}$$

where

$$N_k = 5^4 = 625 \tag{64}$$

is the number of sets for the static determined full factorial plan PS/DK-5^4 with 4 independent variables and 5 values for each independent variable. It means that comparable information about the experimental unit can be obtain from less than a 5% of the static determined full factorial plan sets.

The realizability criterion for the proposed plan was meet because of an axial point has a value equal 2 (see (17)). By reason of this it is possible to select appropriate pitch diameter of drills for drilling holes for sizing.

3. Results of the experiment

The results of the fatigue tests performed by the described plan of the experiment were presented in tab. 3. The results were presented as the mean fatigue life calculated from 3 repetition of each set of independent variables.

4. Summary

The plan of experiment as an example of using the design of experiment were presented in this paper. The obtained results are the basis for the next stage of evaluation of the selected factors effect on the fatigue life of specimens with sized and riveted hole: statistical analyses for determining the adequacy of the proposed mathematical model of the experimental unit. Those analyses were presented in the second part of this paper.

Tab. 2. Summary of sets for experiment (the template of the experiment)

Number of sets	No. of set *u*	Independent variables							
		coded				real			
		$\breve{x}_1$	$\breve{x}_2$	$\breve{x}_3$	$\breve{x}_4$	x_1	x_2	x_3	x_4
		-	-	-	-	MPa	kN	mm/s	mm
n_k = 16	1	-1	-1	-1	-1	175	9.6	0.05	2.95
	2	+1	-1	-1	-1	225	9.6	0.05	2.95
	3	-1	+1	-1	-1	175	11.8	0.05	2.95
	4	+1	+1	-1	-1	225	11.8	0.05	2.95
	5	-1	-1	+1	-1	175	9.6	0.11	2.95
	6	+1	-1	+1	-1	225	9.6	0.11	2.95
	7	-1	+1	+1	-1	175	11.8	0.11	2.95
	8	+1	+1	+1	-1	225	11.8	0.11	2.95
	9	-1	-1	-1	+1	175	9.6	0.05	3.05
	10	+1	-1	-1	+1	225	9.6	0.05	3.05
	11	-1	+1	-1	+1	175	11.8	0.05	3.05
	12	+1	+1	-1	+1	225	11.8	0.05	3.05
	13	-1	-1	+1	+1	175	9.6	0.11	3.05
	14	+1	-1	+1	+1	225	9.6	0.11	3.05
	15	-1	+1	+1	+1	175	11.8	0.11	3.05
	16	+1	+1	+1	+1	225	11.8	0.11	3.05
n_α = 8	17	$+\alpha$	0	0	0	250	10.7	0.08	3.0
	18	$-\alpha$	0	0	0	150	10.7	0.08	3.0
	19	0	$+\alpha$	0	0	200	12.9	0.08	3.0
	20	0	$-\alpha$	0	0	200	8.5	0.08	3.0
	21	0	0	$+\alpha$	0	200	10.7	0.14	3.0
	22	0	0	$-\alpha$	0	200	10.7	0.02	3.0
	23	0	0	0	$+\alpha$	200	10.7	0.08	3.1
	24	0	0	0	$-\alpha$	200	10.7	0.08	2.9
n_0 = 7	25	0	0	0	0	200	10.7	0.08	3.0
	26	0	0	0	0	200	10.7	0.08	3.0
	27	0	0	0	0	200	10.7	0.08	3.0
	28	0	0	0	0	200	10.7	0.08	3.0
	29	0	0	0	0	200	10.7	0.08	3.0
	30	0	0	0	0	200	10.7	0.08	3.0
	31	0	0	0	0	200	10.7	0.08	3.0

Tab. 3. Summary of the results of the experiment

No. of set u	Independent variables								Mean fatigue life	Dependent variable
	coded				real					
	$\breve{x}_1$	$\breve{x}_2$	$\breve{x}_3$	$\breve{x}_4$	x_1	x_2	x_3	x_4	$\overline{N}$	$\overline{y} = \log \overline{N}$
	-	-	-	-	MPa	kN	mm/s	mm	cycle	-
1	-1	-1	-1	-1	175	9.6	0.05	2.95	609 489	5.785
2	1	-1	-1	-1	225	9.6	0.05	2.95	119 939	5.078
3	-1	1	-1	-1	175	11.8	0.05	2.95	625 525	5.796
4	1	1	-1	-1	225	11.8	0.05	2.95	121 441	5.083
5	-1	-1	1	-1	175	9.6	0.11	2.95	614 175	5.788
6	1	-1	1	-1	225	9.6	0.11	2.95	115 099	5.061
7	-1	1	1	-1	175	11.8	0.11	2.95	620 271	5.793
8	1	1	1	-1	225	11.8	0.11	2.95	124 273	5.094
9	-1	-1	-1	1	175	9.6	0.05	3.05	169 358	5.228
10	1	-1	-1	1	225	9.6	0.05	3.05	48 896	4.684
11	-1	1	-1	1	175	11.8	0.05	3.05	192 778	5.285
12	1	1	-1	1	225	11.8	0.05	3.05	54 597	4.734
13	-1	-1	1	1	175	9.6	0.11	3.05	163 210	5.212
14	1	-1	1	1	225	9.6	0.11	3.05	45 667	4.657
15	-1	1	1	1	175	11.8	0.11	3.05	185 947	5.269
16	1	1	1	1	225	11.8	0.11	3.05	51 635	4.711
17	$+\alpha$	0	0	0	250	10.7	0.08	3.0	48 512	4.680
18	$-\alpha$	0	0	0	150	10.7	0.08	3.0	1 163 303	6.065
19	0	$+\alpha$	0	0	200	12.9	0.08	3.0	192 974	5.284
20	0	$-\alpha$	0	0	200	8.5	0.08	3.0	171 473	5.234
21	0	0	$+\alpha$	0	200	10.7	0.14	3.0	195 577	5.291
22	0	0	$-\alpha$	0	200	10.7	0.02	3.0	199 007	5.298
23	0	0	0	$+\alpha$	200	10.7	0.08	3.1	43 414	4.636
24	0	0	0	$-\alpha$	200	10.7	0.08	2.9	365 636	5.562
25	0	0	0	0	200	10.7	0.08	3.0	208 829	5.319
26	0	0	0	0	200	10.7	0.08	3.0	191 698	5.282
27	0	0	0	0	200	10.7	0.08	3.0	202 717	5.306
28	0	0	0	0	200	10.7	0.08	3.0	187 171	5.271
29	0	0	0	0	200	10.7	0.08	3.0	190 578	5.279
30	0	0	0	0	200	10.7	0.08	3.0	205 034	5.312
31	0	0	0	0	200	10.7	0.08	3.0	188 257	5.274

References

[1] 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.

[2] Klonecki W., *Statystyka dla inżynierów*, PWN, Warszawa 1999.

[3] Korzyński M., *Metodyka eksperymentu*, WNT, Warszawa 2006.

[4] Kukiełka L., *Podstawy badań inżynierskich*, PWN, Warszawa 2002.

[5] Lipski A., Mroziński S., Lis Z., *Evaluation of the rivet hole sizing degree effect on the fatigue life*, Journal of Polish CIMAC, Vol. 6, No. 3, 2011, pp. 119-125.

[6] Polański Z., *Planowanie doświadczeń w technice*, PWN, Warszawa 1984.

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

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