Archives of Materials Science and Engineering

Volume 125
Issue 2
February 2024
Pages 58-64

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

DOI: 10.5604/01.3001.0054.5853

Analysis of fillet weld leg length in a low-carbon steel

H.R. Ghazvinloo
Department of Mechanical Engineering, Qom University of Technology, Qom, Iran
Corresponding e-mail address: ghazvinloo@qut.ac.ir
ORCID identifier: https://orcid.org/0000-0003-4251-6315

ABSTRACT

Purpose: The present article analysed the effect of MAG welding parameters (arc voltage-AV, wire feeding speed-WFS, and welding speed-WS) on fillet weld leg length (FWLL) in low-carbon steel S235JR.

Design/methodology/approach: In the research, the Taguchi L8 orthogonal array was used to design experiments. The eight experimental experiments were designed based on the Taguchi method, and the average FWLL was measured in each experiment. The analysis of means (ANOM) and analysis of variance (ANOVA) techniques were used to analyse FWLL.

Findings: The highest F-value in ANOVA analysis (96.08) confirmed that the welding speed is the most effective parameter on the response (with a per cent contribution of 92.24%), followed by wire feeding speed and arc voltage, with an F-value of 2.82 and 1.25, respectively.

Research limitations/implications: The research was focused on MAG welding as a common process used in different industries. Future studies could consider the effect of parameters on fillet weld leg length in other arc welding processes. Due to its many applications in various industries, the low-carbon steel S235JR plate was chosen as the base material, while other steels can be used for future studies.

Practical implications: The findings of the present study have significant practical implications for the welding industry. The design of welding joints is a very important part of the design of metal structures. A weld bead with correct and optimal sizes is desirable and accepted in the design of metal structures. The findings of the present study can be used in the optimal design of fillet welds for low-carbon steel.

Originality/value: As far as we know, there is relatively little information on the proper balance of fillet weld leg length in low-carbon steels. Therefore, the research results can be used in the appropriate design of welding joints for low-carbon steels.

Keywords: Low-carbon steel, Fillet weld leg length, Taguchi method, ANOM, ANOVA

Reference to this paper should be given in the following way:

H.R. Ghazvinloo, Analysis of fillet weld leg length in a low-carbon steel, Archives of Materials Science and Engineering 125/2 (2024) 58-64. DOI: https://doi.org/10.5604/01.3001.0054.5853

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Welding is one of the most applicable connection processes in the industry [1]. Unlike bolts and rivets, a welded joint is permanent and rigid, and it is used in the automotive industry, pressure vessels, shipbuilding, railways, and bridges. Numerous metallic materials can be joined using various welding methods, including friction stir welding (FSW), friction stirs spot welding (FSSW), ultrasonic welding (USW), gas tungsten arc welding (GTAW), laser beam welding (LBW), gas metal arc welding (GMAW), and arc stud welding (ASW). The processes include different advantages and disadvantages in terms of time, temperature, training, cost, appropriateness, efficiency, labour and simplicity [2-7]. The GMAW process, consisting of two modes, "metal–inert gas" (MIG) and "metal–active gas" (MAG), was introduced in the early 1900s. In 1948, the process became commercially accessible [8,9]. For many decades, the MAG process has been used in different industries due to its numerous advantages, including simple mechanism, high productivity and quality, satisfactory mechanical properties of welding joints, and a wide range of weldable materials and filler materials [10,11]. Carbon steel as an iron-carbon alloy is widely used in the industry for moderate and service requirements [12]. Depending on carbon content, carbon steels are divided into three main groups: (i) low-carbon steels, (ii) medium-carbon steels, and (iii) high-carbon steels. Due to their better weldability, formability, and machinability, low-carbon steels are mainly used in the construction and automotive industries. The weld bead geometry characteristics affect the weld quality and welding cost. Generally, a fillet weld has a roughly triangular cross-section with two equal leg lengths and a concave, convex, or flat face. Fillet weld leg length (FWLL) is a substantial parameter in welding because it can strongly affect the welding joint strength and integrity. A low FWLL reduces weld cross-section and thus reduces the strength of the fillet weld joint.

On the other hand, an excessive FWLL can lead to different welding defects and an increased cost and weight for the final product. Hence, finding the proper balance for FWLL in the welding process is important and quite helpful. As far as we know, there is relatively little information on the proper balance of FWLL in low-carbon steels. Therefore, the study tried to analyse the effect of MAG welding parameters on FWLL in low-carbon steel S235JR.

2. Materials and methods

Due to its many applications in various industries, low-carbon steel S235JR plates with a thickness of 4 mm were chosen as a base material in this research. In addition, AWS A5.18 ER70S-6 copper-coated welding wire with a diameter of 1 mm and composition of 0.11C-1.63Mn-0.95Si-0.5Cu (wt. %) was used as a filler metal. A Revo MIG SP-1601 machine was used to fabricate fillet weld joints in the horizontal position (2F), and the weld pools were protected using 100% CO_2 shielding gas. In this study, arc voltage (AV), wire feeding speed (WFS), and welding speed (WS) were selected as control factors at two levels, and their effects on FWLL (response) were investigated and analyzed. Table 1 shows the control factors and their values in two levels. The design of experiments (DOE) method in this study was carried out using the Taguchi L8 orthogonal array. After completing the welding operations, the FWLL was measured for all the welding samples using a Cambridge welding gauge (according to Fig. 1). Table 2 shows the eight experimental experiments designed based on the Taguchi method and the average FWLL measured in each experiment. Analysis of means (known as ANOM) and analysis of variance (known as ANOVA) techniques were used to analyse FWLL. This study selected the "nominal-is-best (NB)" criterion for FWLL, and the means were calculated. The statistical analysis was implemented using ANOVA with a 95% confidence interval to identify the most significant factors affecting the FWLL.

Table 1.
Control factors and their levels

Control factor	Symbol	Unit	Level-1	Level-2
Arc voltage	AV	V	19	21
Wire feeding speed	WFS	m/min	3	4
Welding speed	WS	mm/s	2.2	4.5

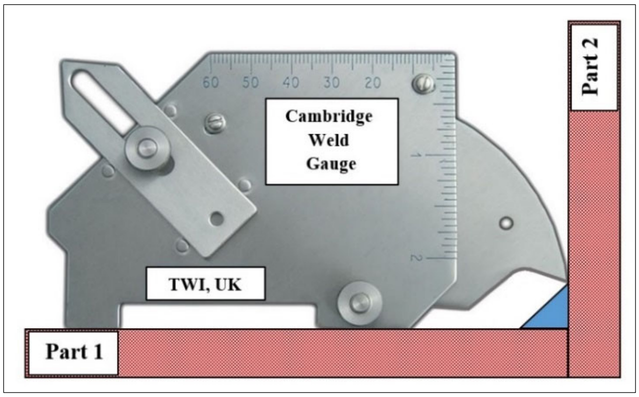

Fig. 1. The measurement method of FWLL using a Cambridge welding gauge

Table 2.
Standard Taguchi orthogonal and average FWLL

Run	AV	WFS	WS	FWLL, mm
1	1	1	1	6.5
2	1	1	2	4.6
3	1	2	1	6.9
4	1	2	2	5.2
5	2	1	1	7.0
6	2	1	2	4.9
7	2	2	1	6.7
8	2	2	2	5.4

Furthermore, the percentage of contribution for each factor was determined according to the results of ANOVA. Finally, a mathematical model was developed to predict the FWLL regarding welding parameters. For such an aim, a linear regression model was developed using the MINITAB 17 statistical software for the FWLL in terms of parameters AV, WFS, and WS.

3. Results and discussion

Figure 2 shows the fillet welded samples at parametric combinations given in Table 2. The FWLL varied from 4.6 mm to 7 mm for different combinations in the study. The mean values of FWLL for each parameter at two levels are given in Table 3 and Figure 3 using MINITAB statistical software. Delta means the difference between the maximum and minimum response values for each parameter, and Rank is the rank of each Delta, where Rank 1 corresponds to the largest Delta. Higher Delta values designate a higher relative effect of the parameter on the response. Table 3 shows WS and AV had the greatest and least effects on FWLL, respectively. As the calculated lines for AV and WFS in Figure 3 are nearly horizontal, these parameters have no significant effect on the response compared to parameter WS.

Table 3.
ANOM: Response table for means

Level	AV, V	WFS, m/min	WS, mm/s
1	5.8	5.75	6.775
2	6.0	6.05	5.025
Delta	0.2	0.30	1.750
Rank	3	2	1

Table 4 presents the ANOVA results for the study. In general, an ANOVA analysis with an accuracy of 95-100% (error rate ≤ 5%) is acceptable, and the error rate in this study was 3.84%. Percent contribution for a parameter indicates the relative power of that parameter to reduce variation. A small variation will greatly affect the performance for a parameter with a higher percentage contribution [13]. According to the ANOVA results, the parameter WS has the greatest effect on the FWLL with a contribution of 92.24%, and parameters WFS and AV (with contributions of 2.71% and 1.20%, respectively) have lower effects on FWLL. The final linear regression model with coefficient values is represented by Equation 1. From the ANOVA results of linear regression for the FWLL, the P-value of 0.003 for the regression equation indicated that the regression model is significant.

$$\text{FWLL (mm)} = 5.4 + 0.1\ \text{AV (V)} + 0.3\ \text{WFS (m/min)} - 0.8\ \text{WS (mm/s)} \quad (1)$$

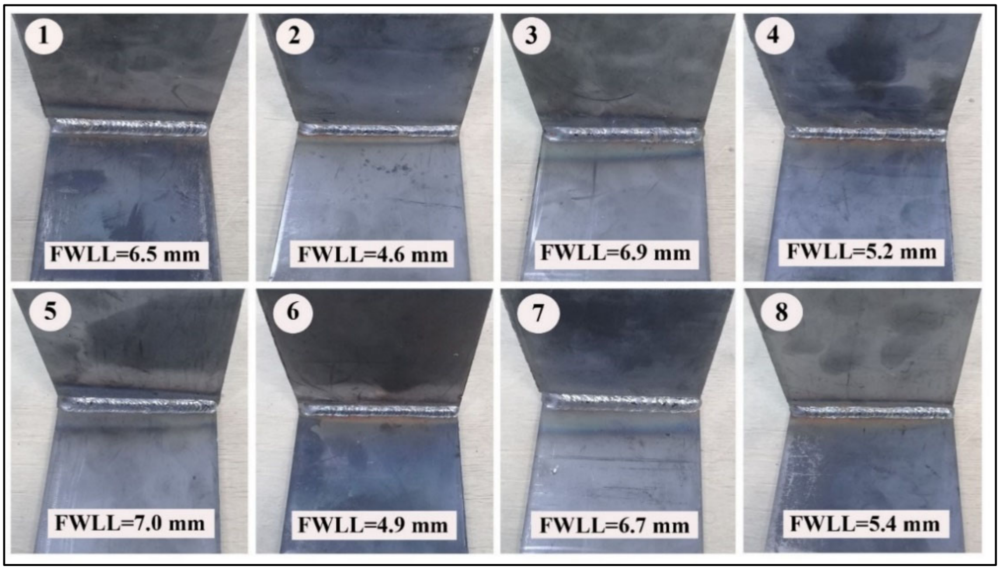

Fig. 2. The fillet welded samples at parametric combinations are given in Table 2

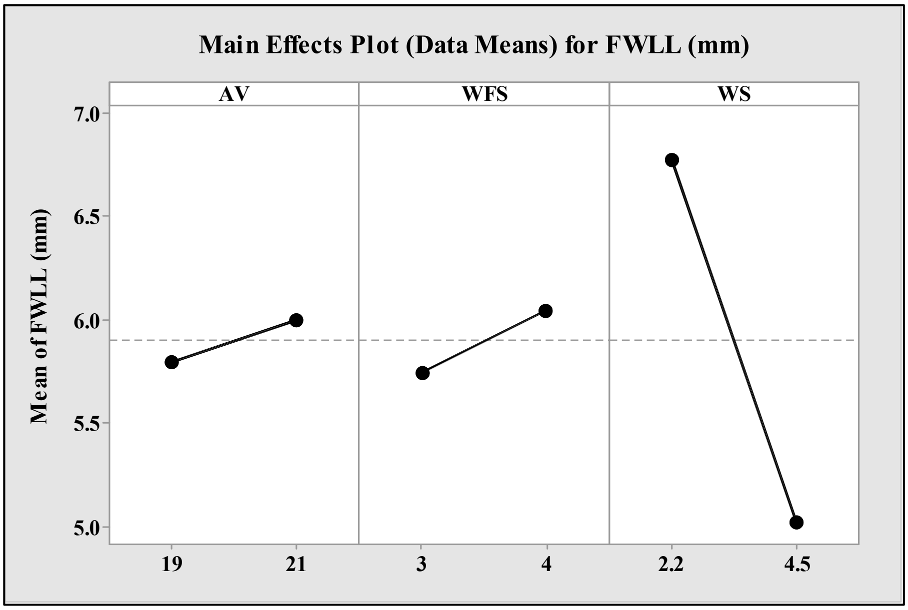

Fig. 3. Main effects plot for FWLL

Table 4.
ANOVA table for FWLL

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution, %
Regression	3	6.39	2.13	33.39	0.003	
AV	1	0.08	0.08	1.25	0.325	1.20
WFS	1	0.18	0.18	2.82	0.168	2.71
WS	1	6.13	6.13	96.08	0.001	92.24
Error	4	0.26	0.06			3.84
Total	7	6.64				100

Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.25	96.16%	93.28%	84.64%

The coefficient of determination (R-squared value) in the ANOVA measures the strength of the linear relationship between experimental and predicted values [14]. In other words, the R-squared value indicates the ability of a model to make predictions. A higher R-squared value is more favourable and indicates a better fit to the regression model. The R-squared value of 96.16% in this work was desirable and indicated a good fit for the regression model, and the data closely followed a straight line. A low P-value (< 0.05) means that we can reject the null hypothesis [15]. If the P-value in ANOVA is lower than the significance level ($\alpha = 0.05$), it means that the parameter corresponding to that P-value is statistically significant for the regression model. Hence, a P-value of 0.001 for parameter WS in this work indicated that (unlike AV and WFS) it has a statistically significant effect on the response of FWLL at the 95% confidence level. The F-ratio (named after Fisher [16]) is used to determine the significant parameters that affect the response. The higher F-value for a parameter corresponds to the lower P-value for that parameter and specifies that the variation of that parameter has a greater effect on the response. The highest F-value obtained in this work (96.08) confirms that the parameter WS is the most effective parameter on response, followed by parameters WFS and AV, with an F-value of 2.82 and 1.25, respectively.

Figure 4 shows the result of the residual analysis for the FWLL. Examination of residuals assists in checking model adequacy [17]. The normal probability plot of the residuals for this model was approximately a diagonal line (straight line at 45°), which indicates that the residuals have roughly

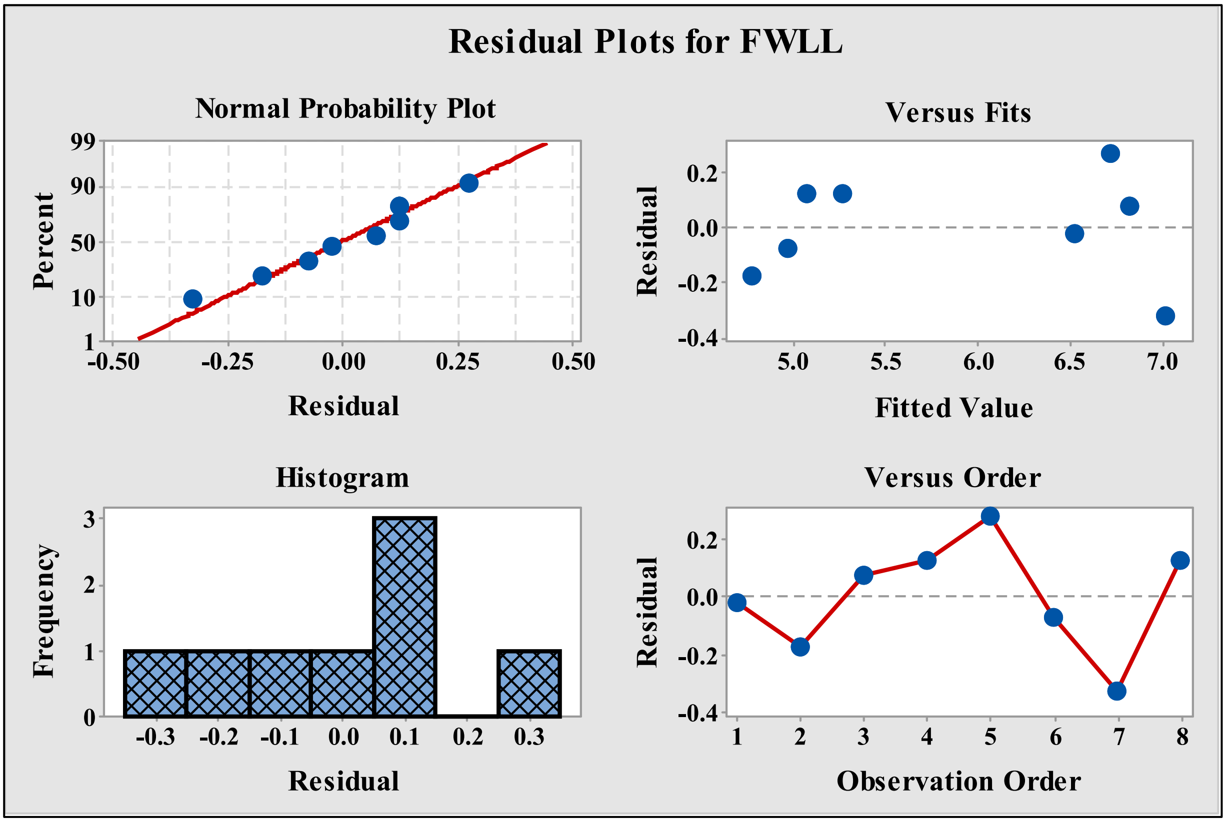

Fig. 4. Residual plots for FWLL

followed a normal distribution. The histogram of residuals revealed that most of the residuals for the model fall around zero and are approximately normally distributed. The residuals are fairly randomly distributed in the residual versus fitted value plot. They are scattered equally around and on both sides of the zero-centre line with no distinct pattern, showing a linear relationship between the predictors and the response variable in this model. The residuals are randomly distributed around the centre line of zero in the residual versus observation order plot. No particular (obvious) pattern or unusual structure can be recognized in this plot. This means that residuals are uncorrelated with each other, which is a reasonable result and proves the absence of systematic faults in the system.

4. Conclusions

Numerical analysis has been used in many literatures [18-22]. The research analysed the effect of MAG welding parameters (arc voltage, wire feeding speed, and welding speed) on fillet weld leg length in low-carbon steel S235JR. The Taguchi L8 orthogonal array was used to design experiments, and ANOM and ANOVA techniques (with an error rate of 3.84%) were applied to the statistical analysis. Among the studied parameters, welding speed was the most significant parameter that affected response, with a per cent contribution of 92.24%. In contrast, arc voltage and wire feeding speed had less effect on the response. A linear regression model was developed with a P-value of 0.003, which indicated that the regression model was significant. In the study, an R-squared value equal to 96.16% obtained in the ANOVA technique was desirable. It showed a satisfactory fit to the regression model, and the data followed a straight line.

Research funding

The research is self-funded.

References

[1] M. Mousavi Anzehaee, M. Haeri, Welding current and arc voltage control in a GMAW process using

ARMarkov-based MPC, Control Engineering Practice 19/12 (2011) 1408-1422.
DOI: https://doi.org/10.1016/j.conengprac.2011.07.015

[2] D. Zhao, K. Zhao, D. Ren, X. Guo, Ultrasonic welding of magnesium–titanium dissimilar metals: A study on influences of welding parameters on mechanical property by experimentation and artificial neural network, Journal of Manufacturing Science and Engineering 139/3 (2017) 031019.
DOI: https://doi.org/10.1115/1.4035539

[3] L. Huang, D. Wu, X. Hua, S. Liu, Z. Jiang, F. Li, H. Wang, S. Shi, Effect of the welding direction on the microstructural characterization in fiber laser-GMAW hybrid welding of 5083 aluminum alloy, Journal of Manufacturing Processes 31 (2018) 514-522. DOI: https://doi.org/10.1016/j.jmapro.2017.12.010

[4] M. Habibi, R. Hashemi, M.F. Tafti, A. Assempour, Experimental investigation of mechanical properties, formability and forming limit diagrams for tailor-welded blanks produced by friction stir welding, Journal of Manufacturing Processes 31 (2018) 310-323.
DOI: https://doi.org/10.1016/j.jmapro.2017.11.009

[5] J. Yang, Z. Yu, Y. Li, H. Zhang, N. Zhou, Laser welding/brazing of 5182 aluminum alloy to ZEK100 magnesium alloy using a nickel interlayer, Science and Technology of Welding and Joining 23/7 (2018) 543-550. DOI: https://doi.org/10.1080/13621718.2018.1425182

[6] V. Kumar, M. Hussain, M.S. Raza, A.K. Das, N.K. Singh, Fiber laser welding of thin nickel sheets in air and water medium, Arabian Journal for Science and Engineering 42 (2017) 1765-1773.
DOI: https://doi.org/10.1007/s13369-016-2305-1

[7] K. Krasnowski, Experimental study of FSW T-joints of EN-AW 6082-T6 and their behavior under static loads, Arabian Journal for Science and Engineering 39 (2014) 9083-9092. DOI: https://doi.org/10.1007/s13369-014-1465-0

[8] S. Zielinska, F. Valensi, N. Pellerin, S. Pellerin, K. Musioł, Ch. de Izarra, F. Briand, Microstructural analysis of the anode in gas metal arc welding (GMAW), Journal of Materials Processing Technology 209/7 (2009) 3581-3591.
DOI: https://doi.org/10.1016/j.jmatprotec.2008.08.023

[9] R. O'Brien (ed), Welding Handbook: Welding Processes, 8th Edition, American Welding Society, Miami, 1991, 786-798.

[10] S. Klarić, I. Samardžić, I. Kladarić, MAG welding process-analysis of welding parameter influence on joint geometry, Proceedings of the 12th International Research / Expert Conference, Istanbul, Turkey, 2008, 185.

[11] A. Ampaiboon, O.-U. Lasunon, B. Bubphachot, Optimization and prediction of ultimate tensile strength in metal active gas welding, The Scientific World Journal 2015 (2015) 831912.
DOI: https://doi.org/10.1155/2015/831912

[12] M. Sailender, G. Chandra Mohan Reddy, S. Venkatesh, Influences of process parameters on heat affected zone in submerged arc welding of low carbon steel, American Journal of Materials Science 6/4A (2016) 102-108.
DOI: https://doi.org/10.5923/c.materials.201601.20

[13] H. Mohamed, M.H. Lee, M. Sarahintu, S. Salleh, B. Sanugi, The use of Taguchi method to determine factors affecting the performance of destination sequence distance vector routing protocol in mobile Ad Hoc networks, Journal of Mathematics and Statistics 4/4 (2008) 194-198.
DOI: https://doi.org/10.3844/jmssp.2008.194.198

[14] A. Rajendran, M. Thirugnanam, V. Thangavelu, Statistical evaluation of medium components by Plackett-Burman experimental design and kinetic modeling of lipase production by Pseudomonas fluorescens, Indian Journal of Biotechnology 6 (2007) 469-478.

[15] Design-Expert Software, Version 6, User's Guide, Technical Manual, Stat-Ease, Minneapolis, MN-2000.

[16] H.R. Lindman, Analysis of variance in experimental design, 1st Edition, Springer-Verlag, New York, 1992, 13-45. DOI: https://doi.org/10.1007/978-1-4613-9722-9

[17] D.C. Montgomery, Design and analysis of experiments, 7th Edition, John Wiley & Sons, Inc., Asia, 2009, 1-22, 60-114, 207-263.

[18] M.A. Hassan, M. Ali, O.I. Abdullah, Numerical analysis of the thermal behaviour and performance of a brake system with temperature-dependent material properties, Archives of Materials Science and Engineering 122/2 (2023) 58-69.
DOI: https://doi.org/10.5604/01.3001.0053.9592

[19] T. Linek, T. Tański, W. Borek, Numerical analysis of the cavitation effect occurring on the surface of steel constructional elements, Archives of Materials Science and Engineering 85/1 (2017) 24-34.
DOI: https://doi.org/10.5604/01.3001.0010.1555

[20] P. Baras, J. Sawicki, Numerical analysis of mechanical properties of 3D printed aluminium components with variable core infill values, Journal of Achievements in Materials and Manufacturing Engineering 103/1 (2020) 16-24.
DOI: https://doi.org/10.5604/01.3001.0014.6912

[21] P. Kuryło, K. Zaborowska, P. Czarnecki, P. Pruszyński, Numerical analysis of propagation of femur crack due to osteoporotic changes, Journal of Achievements in Materials and Manufacturing Engineering 121/2 (2023) 320-326.
DOI: https://doi.org/10.5604/01.3001.0054.3213

[22] P. Shenbaga Velu, N. Rajesh Jesudoss Hynes, Numerical analysis of friction welded titanium joints, Journal of Achievements in Materials and Manufacturing Engineering 76/1 (2016) 26-29. DOI: https://doi.org/10.5604/17348412.1228630