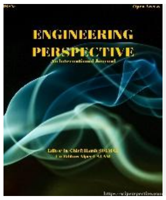

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Research Paper

The Effect of Welding Wire Feed Speed on Weld Bead Penetration, Length and Width in Robotic Gas Metal Arc Welding

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ABSTRACT

In this study, the effect of welding wire feed speed on penetration quality in the gas metal arc welding method (GMAW), which is widely used in the automotive industry, was investigated in terms of product safety and quality. In the gas metal arc welding robots used in automotive production, the welding process is carried out through communication between the robot and the gas metal arc welding machine within predetermined parameters. In the study, 3 mm thick 6224 ERD steel was used and overlap welding was applied for experimental analysis. Among the gas metal arc welding parameters, welding current, wire diameter, and gas flow rate were kept constant, while wire feed speed was considered as the only variable. Starting from 2 m/min, the welding wire feed speed was increased by 2 m/min in each test, reaching up to 12 m/min, resulting in a total of 6 different experiments. The test results were evaluated based on metallographic analyses to determine the macro and microstructures of the welds. According to the findings, it was observed that penetration increased as the welding wire feed speed increased. However, it was also determined that beyond a certain optimum value, the increased welding speed had a negative effect on weld bead width and length. Accordingly, the optimum welding wire feed speed was suggested for achieving the appropriate penetration and maintaining weld quality.

Keywords: Robotic arc welding; penetration; welding wire feed speed

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1. Introduction

The continuous growth of the global population has led to a substantial increase in energy demand [1]. This situation has intensified competition among companies and generated a strong expectation for manufacturing methods that simultaneously offer high quality and low production costs. The utilisation of robots in gas welding has become pervasive to enhance customer satisfaction and ensure product quality. To mitigate human-related errors, gas welding operations are increasingly conducted with a robot serving as the carrier. This method is favoured by manufacturers seeking to produce welds that are free of errors, while maintaining minimal production time and maintaining product quality at a certain level [2-4]. The effect of wire feed speed on weld penetration depth in GMAW welding has been demonstrated to be significant for many types of metallic materials. As the wire feed speed increases, the welding current also increases in the constant voltage weld supply systems, which in turn increases the heat input and weld penetration depth [5-8]. However, this relationship between wire feed rate and penetration and also weld current may not be linear. At elevated wire feed speeds, the collective travel speed necessary to sustain a stable weld pool can counteract some of the benefits gained from elevated current values. Furthermore, the arc becomes more constricted at higher wire feed speeds, which can marginally reduce penetration due to reduced amount of heat input into the weld pool of which its average temperature between the center and the edge of the weld pool is considerably different; a condition of high cooling rate due to small volume of weld pool [9-12]. Higher wire speeds can result in a more constricted arc, which can slightly reduce penetration and lowering wire speed can be advantageous for specific joints, such as outside corners, to prevent excessive penetration and regulate the weld profile. In addition, it can be concluded that wire feed speed is one of the most significant factors controlling weld penetration in GMAW welding. While increasing wire feed speed does indeed increase penetration, the relationship is complex and further factors, such as travel speed, must be considered. Adjusting wire feed speed is a key method by which welders can control and optimize weld penetration [13-16, 17]. Wire feed speed is one of the most important factors controlling weld penetration, but its effect is complex and interactive with welding speed. Increasing wire speed leads to increased penetration, but at very high speeds, faster travel becomes necessary, which can counteract this gain. It is therefore essential for welders to adjust both parameters to optimize weld penetration for each specific welding application [5, 18-21].

In this study, the effect of welding wire feed speed on penetration was investigated by overlap welding with 3 mm thick 6224 ERD steel on a gas metal arc welding robot. The weld wire feed rate was chosen between 2 m/min and 12 m/min. Metallographic investigation was carried out for determining the penetration and weld macro and microstructures.

2. Materials and Methods

2.1 Material

2.1.1 6224 ERD steel sheet material, SG2 welding wire and shielding gas

The chemical composition of the 3 mm thick uncoated commercial 6224 ERD steel used in the experiments is shown in Table 1 and its mechanical properties are shown in Table 2.

Table 1. Chemical content of 3 mm 6224 ERD steel sheet (wt. %).

C	P	S	Mn	Al
0,07	0,015	0,015	0,35	0,02

Table 2. Mechanical properties of 3 mm thick 6224 ERD sheet metal

Yield Stress (MPa)	170
Tensile Stress (MPa)	400
Elongation (%)	33

SG2 quality 1 mm welding wire was used as the welding wire and its chemical composition is shown in Table 3 and mechanical properties are shown in Table 4.

Table 3. Chemical composition of SG2 (1 mm) welding wire (wt.%).

C	Si	Mn	P	S
0,06	0,41	1,1	0,012	0,011

Table 4. Mechanical properties of SG2 (1 mm) welding wire.

Yield Stress (MPa)	430
Tensile Stress (MPa)	540
Elongation (%)	28
Temperature (°C)	-29
Impact Toughness (J)	70

Tests were conducted with Manifold 205 mixture gas, which is frequently used in industry as a protective gas. The composition properties of the mixture gas are given in Table 5.

Table 5. Gas mixture content of HB 205 standard shield gas (vol. %).

	Ar	CO2	O2
HB 205	93	5	2

By keeping the current constant in the gas welding robot and increasing the welding wire feed speed from 2 m/min to 12 m/min, 6 overlap welds were made and the test pieces were prepared for measuring penetration and microstructural examination.

2.2 Overlap welding with gas welding robot

In this study, an ABB brand robot was integrated with a Fronius TransPuls Synergic 4000 brand MIG welding machine for the welding process. SG2 welding wire was used as the welding wire in this study. Figure 1 shows an image of the MIG welding robot machine. Ensuring that the wire feed speed works with the correct parameters will reduce the consumption of consumable materials such as the contact nozzle. After measuring the gas flow, the welding gas flow was not reduced below 10 litres per minute to prevent welding porosity and ensure penetration. Although gas flow, weld current value and surface cleanliness affect the end result, many variables affecting weld quality, only the wire feed speed was changed. During the test, these variables were kept under control. A Tronic Xjl-17 inverted trinocular metallographic microscope was used for penetration and microstructure images. The robotic GMAW welding operation was performed with six test specimens using the values given in Table 6. The current intensity was kept constant, and the wire feed speed was increased to 2 meters per minute on each part.

Figure 1. Welding robot used in this study

Table 6. Test parameters of weld process

Specimen	Current (A)	Wire feed speed (m/min)	Wire Diameter (mm)	Gas Flow Rate (lt/min)
1. test specimen	135	2	1	10
2. test specimen	135	4	1	10
3. test specimen	135	6	1	10
4. test specimen	135	8	1	10
5. test specimen	135	10	1	10
6. test specimen	135	12	1	10

3. Results and Discussions

3.1 Weld bead properties and penetration

The measured results of the welded bead widths of parts obtained by welding the test samples at different wire feed speeds are shown graphically in Figure 2. As can be seen from the effect of the wire feed speeds, the weld width increases as the amount of weld wire is purged into the weld pool increases i.e. due to the accumulated weld metal volume. The increase in the feeding rate also means there is more weld metal pool volume and hence, the increase in the weld width with the amount of weld metal positively affects the heat input with respect to higher average weld pool temperature [2, 3]. This is related to the frequency of deposition of hot liquid weld metal that is present in the weld zone during the welding process. As the deposition rate increases the average weld pool temperature increases and the heat input is raised due to the elevated number of droplets of liquid metal per unit time. On the other hand, the weld lengths are generally similar as oppose to the weld bead width [17, 19, 21]. The increase in the weld bead width is compensated with weld bead lengths with respect to the wire feed speed which are given in Figure 3.

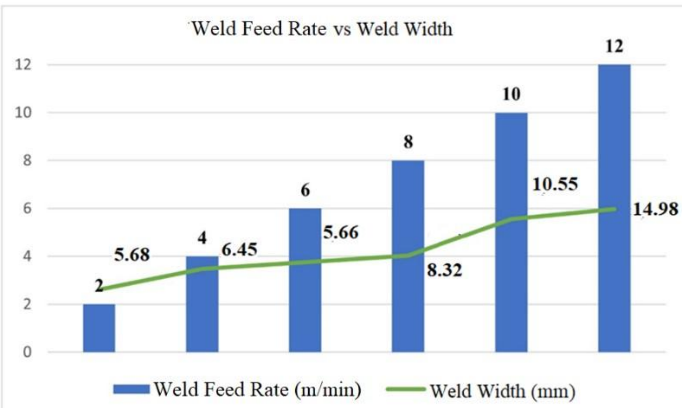

Figure 2. Weld bead width with respect to wire feed speed

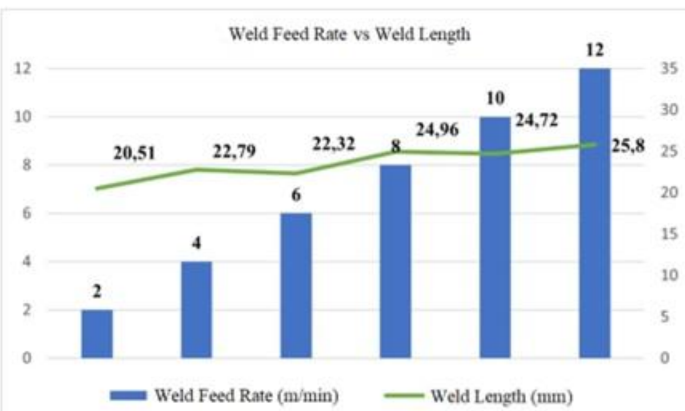

Figure 3. Weld bead length with respect to wire feed speed

After the welding process, the penetration depths were measured and the results are given in Figure 4. According to the results of the tests, the weld width increased as the welding wire feed speed increased. According to the welding image given in Test specimen Figure 5, it is seen that the optimum value of the welding wire feed speed is 10 m/min, and the curve in the graph in Figure 2 shows this. The weld length measurements also give the same result, and the appropriate welding image is obtained at a welding wire feed speed of 10 m/min. After the test process, the penetration depths were measured and the results are given in Figure 4.

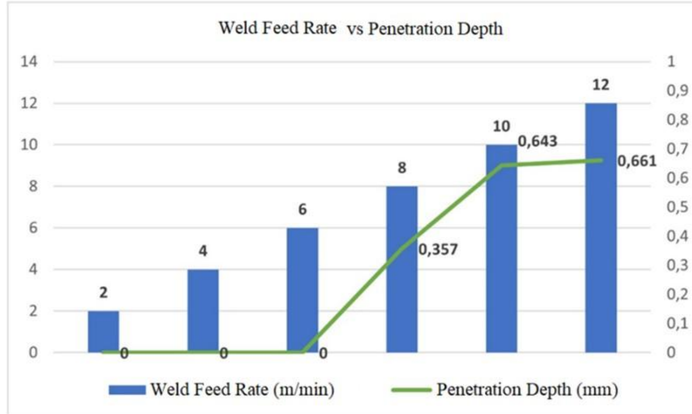

Figure 4. Penetration depths with respect to wire feed rate

As demonstrated in Figure 5, the macro images of the weld seam according to the welding wire feed speed are as follows: at a low welding wire feed rate, the weld seam was found to be spattered and narrow, with an absence of fusion or penetration defects at the edges; conversely, at welding feed rates of 4 m/min and above, the welds were smooth in appearance and exhibited minimal slag formation on the weld seam. The pene-tration depth desired by the main customer has reached the op-timum value at the welding wire feed speed of 10 m/min, and the penetration depth increases as the welding wire feed speed increases. The penetration depth of 2, 4, 6 m/min was found to be unsuitable in the tests conducted for the production purposes. It is noteworthy that the width of the weld end crater increases with increasing welding wire feed speed, reaching a maximum at a wire feed speed of 12 m/min. This phenomenon can be at-tributed to the rise in the average temperature of the weld seam. The increase in the amount of molten metal, which is caused by an increase in the amount of welding wire rate, results in an in-crease in the temperature of the weld pool. This, in turn, as seen in Figure 5, leads to an increase in the length of the weld crater [3]. As illustrated in Table 10, a clear correlation emerges be-tween the dimensions of weld bead craters and their length. The width-to-length ratio appears to be increasing dramatically above a wire feed speed of 8 m/min, from 0.277 to 0.581 ratio, which is almost double of the original the former value. The crater width-to-length ratio is also significant when compared to the weld bead width-to-length ratio, which records a dramatic jump from 0.312 to 0.579 ratio.

Weld penetration in GMAW welding is significantly influenced by wire feeding speed, as it directly affects the amperage and, consequently, the heat input into the weld. Wire feed rate con-trols the amount of wire fed into the arc, which in turn deter-mines the weld current flow characteristics. Higher current flow generally results in greater heat input and deeper penetration [2, 5, 6]. While faster wire feed speeds increase amperage and po-tentially penetration, they may be offset by the faster travel speeds, increasing penetration effect because less time is spent heating any one area [2, 6, 12]. As the weld travel speed is con-stant in this study, the heating effect is elevated in favour of higher weld pool temperature and therefore larger weld pool size at higher weld wire feed rate.

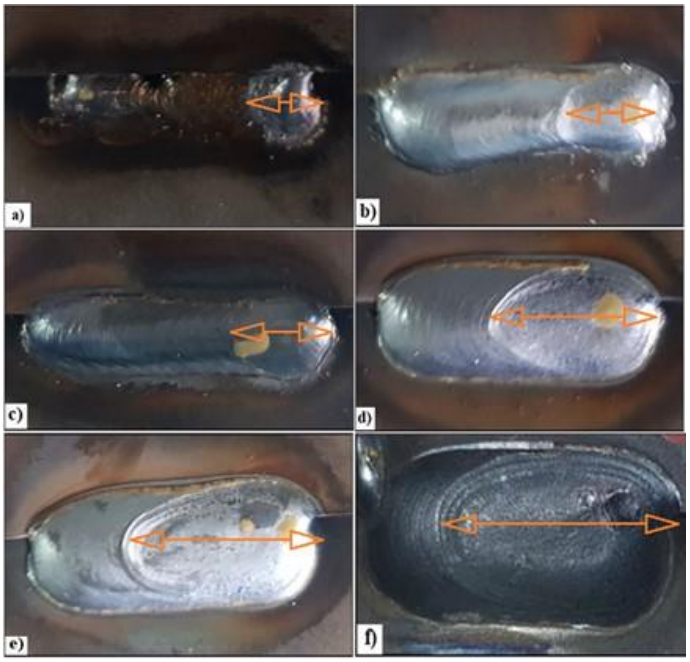

Figure 5. Appearance of GMAW weld beads deposited at dif-ferent weld wire feed rates, a) 2 m/min, b) 4 m/min, c) 6 m/min, d) 8 m/min e) 10 m/min f) 12 m/min.

A well-penetrated weld typically exhibits optimal tie-in at the weld edges and a flat bead profile, whereas insufficient penetra-tion may result in a narrow, convex bead. The relationship between welding speed and penetration depth is inversely proportional; as welding speed increases, penetration depth decreases due to several factors [4, 17, 19]. Faster welding speeds result in reduced time for the arc to heat a specific area, leading to de-creased heat input and shallower penetration. Increased travel speeds result in the weld pool solidifying more rapidly, leading to reduced weld bead width and less time available for penetration. Conversely, slower speeds allow for deeper weld pools to form due to increased time for the base material to melt by absorbing more heat due to heat transfer restrictions in large weld pool volumes. However, slower speeds can also result in improved penetration due to more time for heat to penetrate the metal. However, excessively slow speeds can lead to increased spatter and other defects [19-21]. In summary, increased wire feeding rate results in decreased penetration depth due to reduced heat input and smaller weld pool size, whilst decreased wire feeding speed leads to increased penetration depth due to increased heat input and longer solidification time. The weld length exhibited minimal change with increasing welding wire feed rate, attributable to the constant welding feed rate. However, while no change is expected, the expansion of the weld deposition and the enlargement of the crater due to the effect of the weld heat input indicate that the weld is expanding forward or melting of the front of weld pool during the welding process [3, 13, 21].

As shown in Figure 6, the penetration depths of macrostructures are contingent upon the welding wire feed rate. The analysis of these macrostructures reveals that optimal weld penetration is achieved at weld wire feed rates of 10 m/min and 12 m/min. In contrast, the weld seam appearance at 2, 4, and 6 m/min wire feed rates exhibits minimal penetration, while welds at 8 m/min and above demonstrate substantial penetration. The penetration in the welding process is usually directly related to the heat input, which can be related to the welding wire diameter, welding travel speed and wire feed rate, welding current and arc distance in wire fed systems [3, 4, 11, 14]. As a result of the ex-amination of the macrostructure pictures, the amount of melting in the base metal can be easily seen. While the melting of the base metal is evident at rates exceeding 6 m/min, it is more pro-nounced at welding wire feed rates of 10 m/min and 12 m/min. The melting of base metal is also important in assessing the success of the weld bead. It is noticeable that the melting of upper sheet is not achieved until 8 m/min wire feed rate and the edges of upper sheet metal just under the weld bead disappears at 10 and 12 m/min wire feed rates successfully.

Table 7. The widths (W), lengths (L) and Crater Length (CL) of weld beads with respect to wire feed rate and relevant correlations between W, L and CL values (in mm) .

Wire feed rate (m/min)	Width (W)	Length (L)	Crater Length (CL)	W/L
2	5.68	20.51	6.4	0.277
4	6.45	22.79	6.73	0.283
6	5.66	22.32	7.21	0.254
8	8.32	24.96	12.25	0.333
10	10.55	24.72	13.32	0.427
12	14.98	25.8	14.94	0.581

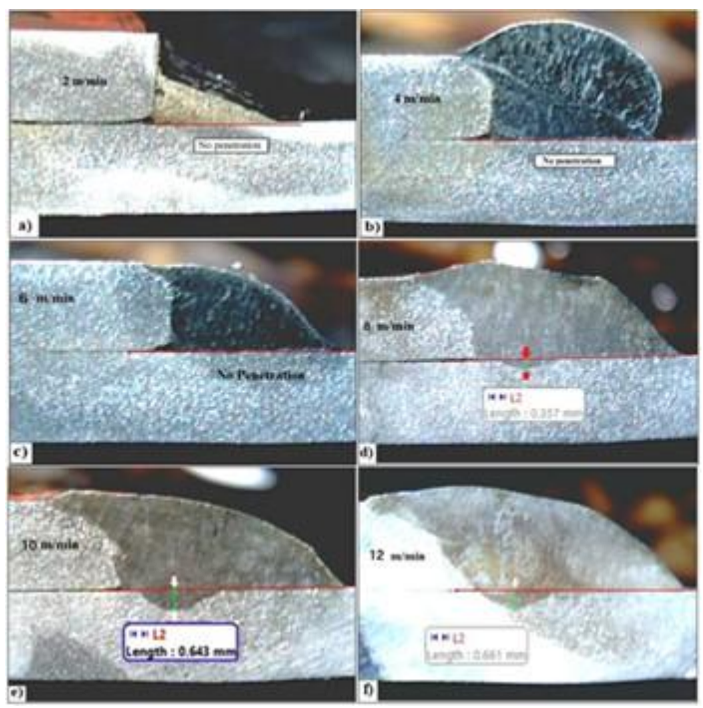

Figure 6. Cross-sectional macrostructures of GMAW weld beads deposited at different welding wire feed rates, a) 2 m/min, b) 4 m/min, c) 6 m/min, d) 8 m/min e) 10 m/min f) 12 m/min

4. Conclusions

The following general results were obtained in this study:

1. The penetration results of robotic welded seams at welding wire feed rates of 2, 4, 6, 10 and 12 m/min show that the optimal wire feed rate is 10 m/min and the critical rate is 8 m/min.

2. As the welding wire feed speed increases, the dimensions of the

weld pool crater resulting from the mostly solidification, also change. With increasing welding wire feed rate, the weld pool solidification crater dimensions increase.

3. It is hypothesised that the formation of a large weld crater as a result of the accumulation of a large amount of weld metal with high welding wire feed rate is due to the high average temperature of the weld pool.

4. The large weld pool crater further underscores the correlation between weld heat input and weld pool temperature.

5. The weld pool width is believed to be associated with the increasing quantity of liquid metal droplets.

6. The weld length exhibited minimal change with increasing welding wire feed rate, attributable to the constant welding feed rate. However, while no change is expected, the expansion of the weld deposition and the enlargement of the crater due to the effect of the weld heat input indicate that the weld is expanding forward or melting of the front of weld pool during the welding process.

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Conflict of Interest Statement

The authors must declare that there is no conflict of interest in the study.

CRediT Author Statement

Mustafa Yazar: Investigation, Project administration, Resources, Writing – original draft **Hilal Kır:** Investigation, Writing – review & editing **Şükrü Talaş:** Conceptualization, Formal analysis, Supervision, Methodology

References

1. Dam, Q.T., Haidar, F., Mama, N., Chennapalli, S. J. (2024). Modeling and simulation of an Internal Combustion Engine using Hydrogen: A MATLAB implementation approach. Engineering Perspective. 4 (3). 108-118. http://dx.doi.org/10.29228/eng.pers.76219
2. Zhao, D., Bezgans, Y., Vdonin, N., Radionova, L., Bykov, V. (2021). Modeling and Optimization of Weld Bead Profile with Varied Welding Stages for Weathering Steel A606. International Journal of advanced Manufacturing Technology. Volume 116. pages 3179–3192. https://doi.org/10.1007/s00170-021-07722-y
3. Lancaster, J. F. (1999) Metallurgy of Welding. Woodhead publishing. ISBN: 978-1-85573-428-9
4. Lertora, E., Gambaro, C., & Cypres, P. (2011). The influence of robotic MAG process welding parameters. Welding International. 25(10). 767–776. https://doi.org/10.1080/09507116.2011.581349
5. Mills, K. C., & Keene, B. J. (1990). Factors affecting variable weld penetration. International Materials Reviews. 35(1). 185–216. https://doi.org/10.1179/095066090790323966
6. Kim, I.S., Son, J.S., Kim, I.G., Kim, J.Y., Kim, O.S. (2003). A study on relationship between process variables and bead penetration for robotic CO2 arc welding. Journal of Materials Processing Technology. 136(1–3). 139–145. https://doi.org/10.1016/S0924-0136(02)01126-3
7. Wu, Y., Kovacevic, R. (2002). Mechanical assisted droplet transfer process in gas metal arc welding. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 216(4). 555–564. https://doi.org/10.1243/0954405021520247
8. Katayama, S., Kawahito, Y., Mizutani, M. (2010). Elucidation of laser welding phenomena and factors affecting weld penetration and welding defects. Physics Procedia. 5(Part B). 9-17. https://doi.org/10.1016/j.phpro.2010.08.024
9. Li, K., Wu, Z.S,, Liu, C.R., Chen, F.H. (2014). Arc characteristics of submerged arc welding with stainless steel wire. International Journal of Minerals, Metallurgy, and Materials. 21(8). 772–778. https://doi.org/10.1007/s12613-014-0970-1
10. Li, X.R., Zhang, Y.M., Kvidahl, L. (2013). Penetration Depth Monitoring and Control in Submerged Arc Welding. Welding Journal Research Supplement. 92. 48s-56s.
11. Ibrahim, I.A., Mohamat, S.A., Amir, A., Ghalib, A. (2012). The effect of gas metal arc welding (GMAW) processes on different welding parameters. Procedia Engineering. 41. 1502–1506. https://doi.org/10.1016/j.proeng.2012.07.342
12. Roshan, R., Kumar Naik, A., Kumar Saxena, K., Arora, K. S., Shajan, N., Msomi, V., & Mehdi, H. (2023). Effect of welding speed and wire feed rate on arc characteristics, weld bead and microstructure in standard and pulsed gas metal arc welding. Journal of Adhesion Science and Technology. 37(23). 3297–3314. https://doi.org/10.1080/01694243.2023.2192314
13. Suban, M., Tušek, J. (2001). Dependence of melting rate in MIG/MAG welding on type of shielding gas. Journal of Materials Processing Technology. 119(1-3). 185–192. https://doi.org/10.1016/S0924-0136(01)00940-2
14. Praveen, P., Yarlagadda, P.K.D.V., Kang, M.J. (2005). Advancements in pulse gas metal arc welding. Journal of Materials Processing Technology. 164–165. 1113–1119. https://doi.org/10.1016/j.jmatprotec.2005.02.100
15. Wang, J., Sun, Q., Ma, J., Jin, P., Sun, T., Feng, J. (2018). Correlation between wire feed speed and external mechanical constraint for enhanced process stability in underwater wet flux-cored arc welding. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 233(10). 2061-2073. https://doi.org/10.1177/0954405418811783
16. Karadeniz, E., Ozsarac, U., & Yildiz, C. (2007). The effect of process parameters on penetration in gas metal arc welding processes. Materials & Design, 28(2), 649–656. https://doi.org/10.1016/j.matdes.2005.07.014
17. Deshmukh, A.R., Venkatachalam, G., Divekar, H., Saraf, M.R.(2014). Effect Of Weld Penetration On Fatigue Life. Procedia Engineering. 97. 783 – 789. https://doi.org/10.1016/j.proeng.2014.12.277
18. J. Tušek (2002). Factors Affecting Weld Shape in Welding With A Triple-Wire Electrode. Metalurgija. 2. 89-92.
19. Mills, K. C., & Keene, B. J. (1990). Factors affecting variable weld penetration. International Materials Reviews, 35(1), 185–216. https://doi.org/10.1179/095066090790323966
20. Lee, K-B., Kim, C., Kim, D-S. (2013). High deposition rate pulse gas metal arc welding for Al 5083 thick plate. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 227(6).848-854. https://doi.org/10.1177/0954405413476860
21. Kozakov, R., Schöpp, H., Gött, G., Sperl, A., Wilhelm, G., & Uhrlandt, D. (2013). Weld pool temperatures of steel S235 while applying a controlled short-circuit gas metal arc welding process and various shielding gases. Journal of Physics D: Applied Physics, 46(47), 475501. https://doi.org/10.1088/0022-3727/46/47/475501