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Influence of the Process Input Parameters on the Cross-Wire Weld Breaking Force

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Abstract: Cross-wire welding is a type of electric resistance welding called projection welding that is used in the production of a variety of products. This paper deals with the case where steel wires of equal radii are joined together to form a reinforced steel mesh. The objective of the study is to determine the correlation between the welding parameters and the breaking force of the weld. Each weld is cut out from the given wire mesh and tested separately by destructive testing on the universal testing machine. A modular testing fixture was constructed for the tests. Although the tests are still in the initial stage, the results already give a good insight into the influence of the process input parameters on the breaking strength of the weld.

Keywords: breaking force; cross-wire welding; destructive testing; electric resistance welding; projection welding; welding

1 INTRODUCTION

Electric resistance welding (ERW) is the welding process that involves passing of an electric current through the components. Heat generated from the electric current joins the components at the interface with no filler material being used [1]. Most common use of this type of welding can be found in the automotive industry. This article however is focused on a different type of resistance welding called cross-wire welding.

Cross-wire welding is the type of the projection welding. Two steel wires of the same radii are joined together to form reinforcing wire mesh. Bushell [2] and Jordan [3] have described mesh production, where multiple welds are being produced at the same time. This paper focuses on this type of production process called, indirect [4] cross-wire welding, with three welds per current flow being made.

Desired setdown between the two steel wires is obtained through variation of the welding parameters. In this case the welding parameters are weld current strength and weld time. As the article by Nielsen et al. [5] states, setdown can be related to the weld strength and is direct measure of compression. Results in [5] are given for the large diameter wire mesh used in reinforcing concrete. This article however analyzes wires of the smaller radii used in production of mass produced products that need to be coated to prevent corrosion.

Every projection welding creates expulsion [4]. Too much expulsion however creates a challenge in the field of corrosion resistance. Welds with small amounts of expulsion are desired if the goal is to achieve required corrosion resistance with the powder coating corrosion protection method.

If the amount of expulsion can be controlled, satisfactory weld appearance can be achieved on every single weld. Satisfactory weld appearance means that the powder coating is easier to apply. This directly reduces the amount of electrostatic powder coating [5] needed to achieve longer corrosion resistance, thus reducing the overall production cost. However, because weld appearance is not the only requirement, expulsion must be controlled without sacrifices being made to the weld strength.

Electric resistance welding on the microscale, as described in [6] is in general the same process as the large-scale resistance welding, but due to the size of the testing sample and dominant stresses that are acting on the sample testing method is different. Experimental research on the micro scale resistance welded joints were mainly focused on the optimizing weld schedules with respect to weld strength and setdown. [5]

Destructive testing method in this case is used to completely break down the weld to determine its breaking force. This is carried out with the specific fixture designed specifically for this test, a sensor that records the force data and the universal testing machine that acts as a press.

Aim of this paper is to define correlation between the variations in the welding parameters and the weld breaking force for obtaining the strongest weld possible with the satisfactory appearance.

2 WELD STRENGTH TEST

2.1 Testing Equipment

According to the Resistance Welding Manual [8] the proper way of testing the strength of the cross-wire weld is with the use of simple fixture and pusher bar. Aim of the project is to determine the strength of the cross-wire welds with the different wire diameters. With this goal in mind, the testing fixture is constructed in a way that it can be quickly adjusted for various wire diameters. Force value at weld breaking point is obtained through the force sensor connected to the PC while the pressure force is introduced with the use of the universal testing machine. Equipement used for the force measurement is Burster 8524 load cell [9] with DigiVision [10] software used to track and store test results. Wire material is specified to be S235 steel and the wire diameter is 4 mm for all tested samples.

Cross-wire weld strength test setup is shown in Fig. 1.

2.2 Pre Test Operations

Before testing, each individual sample is cut from the wire mesh. Then, each weld is photographed with telecentric camera. Although the setdown is predetermined, it is also measured for verification. Storing of the weld images is required for monitoring the influence of the ERW parameters on the amount of expulsion and weld appearance. While this data is also used and monitored in this project, focus of this paper is only on the weld strength testing. Fig. 2 shows an example of the image taken during the setdown measuring phase of the testing.

Figure 1 Cross-wire weld test setup

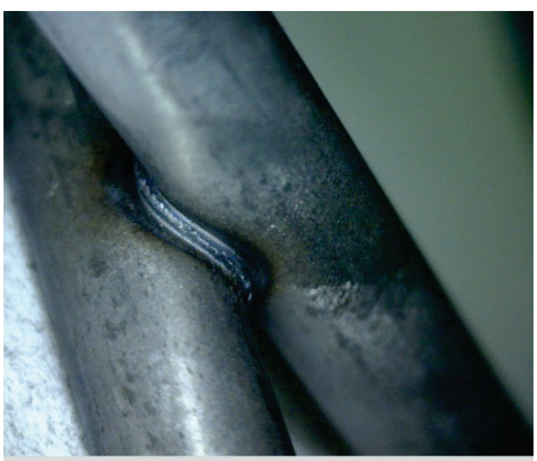

Figure 2 Weld close-up image taken by the microscope

According to the Resistance Welding Manual percent setdown (%) is calculated as:

$$P_s = \frac{A - B}{A} \cdot 100\ \%, \qquad (1)$$

where A is the same diameter as C or smaller as shown in Fig. 3.

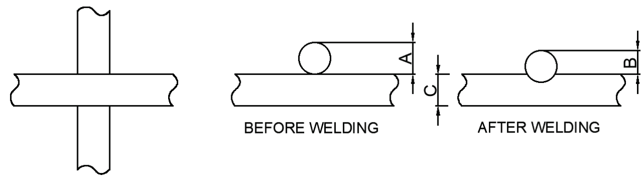

Figure 3 Wire diameters before and after welding

Because of the large amount of testing samples on one testing specimen, wire mesh is divided into the zones, where each zone contains nine samples. Zones and mesh division is shown in the Fig. 4.

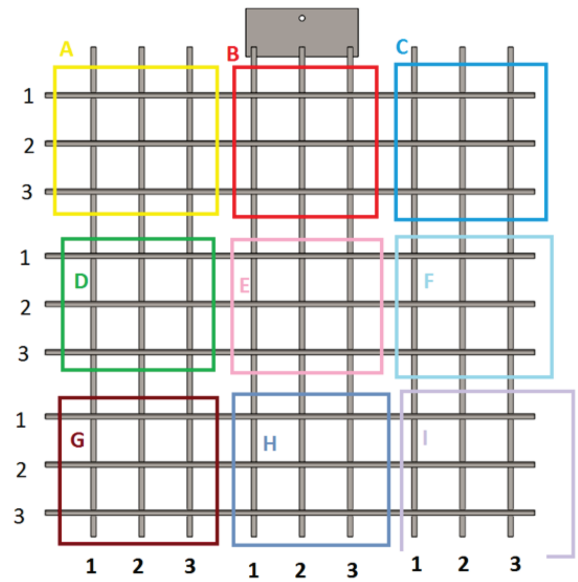

Figure 4 Wire mesh division and zone names shown on the wire mesh sample

After the test is conducted, load cell records the force value, while the sample is destroyed. Example of the destroyed sample is shown in Fig. 5.

Figure 5 Sample after testing

3 RESULTS

This section of the paper shows results of the tests carried out on the seven wire meshes with different parameters. Parameters that were varied for these tests are weld current strength (*A*) and weld time (*t*). Due to the nature of this stage of the project only relative values were given, while the absolute values remain disclosed. Since S235 steel is a low carbon steel, according to [11] for low carbon steels, mechanical properties of the material should be almost identical to the mechanical properties of the weld.

Tab. 1 shows the variations in the parameters for each given wire mesh.

Table 1 Welding parameters variations on the given samples

Mesh sample	Weld current strength variation (%)	Weld time variation (%)
Optimal sample 1	0	0
Optimal sample 2	0	0
Test sample 1	+25	0
Test sample 2	–20	0
Test sample 3	+30	0
Test sample 4	0	–20
Test sample 5	+20	+20

From Tab. 1 we can see that we have two "optimal" samples and five samples with varied parameters. Samples are considered optimal relatively to the weld appearance. On the test samples 1, 2 and 3 there is a variation in the weld current strength. On sample 4, weld time is 20% lower than on the optimal sample, while on the sample 5 the weld current and time are 20% higher regarding optimal samples.

As mentioned before each weld is cut out of the wire mesh and separately tested as described in previous chapter. Each mesh has 81 sample, which adds up to 567 separate test that were conducted and included in presented results.

Fig. 6 shows the average breaking force value for each tested wire mesh.

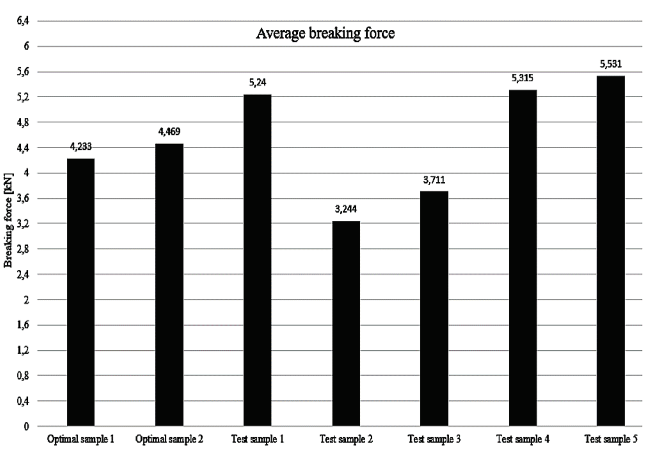

Figure 6 Average values of the weld breaking force

Fig. 7 shows the same results, but presented in a boxplot diagram. This is shown because of the significant deviation in the obtained results on the same mesh sample. Reason for this deviation now is uncertain that it can come from many contributing factors such as; impurities in the material and on the material surface, process stability, welding electrode misalignment, fact that electrode welds three welds simultaneously, etc.

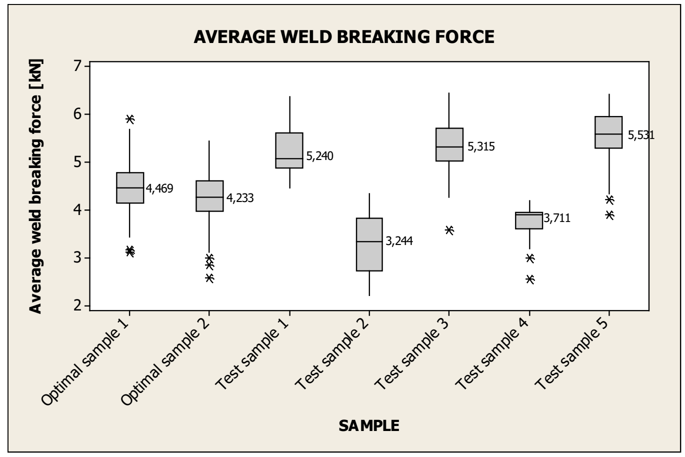

Figure 7 Boxplot of the test results

Despite shown deviations, we can see the trend of the results. Average value of the weld breaking force increases significantly with the increase of the welding current strength, while reducing the weld time has smaller impact on the breaking force. This conclusion is drawn relatively to optimal samples. Reducing the weld current strength, results in the drastic drop of the weld breaking force.

Sample with both welding current strength and the weld time increased by 20% showed the highest average breaking force value.

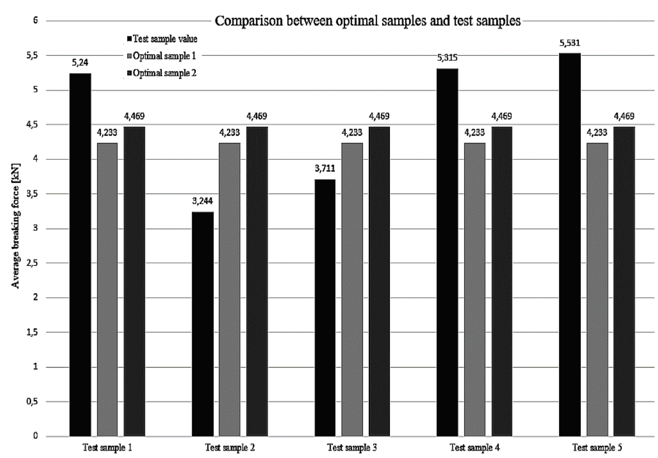

Figure 8 Comparison of average breaking force values between optimal and test samples

4 CONCLUSION

From the tests conducted on the seven-welded wire, meshes with the variations in the parameters can be concluded that parameters of the welding process have significant impact on the weld breaking force.

Samples with increased current strength have shown significant increase in the average breaking force and the increase in both time and current strength resulted in the highest average breaking force value. Reducing the weld current strength resulted in significant drop of average weld breaking force.

Relatively to the optimal samples, sample with decreased weld time has shown no significant decrease in the average breaking force value. From this, it can be concluded that the weld current strength is more significant ERW parameter when it comes to increasing breaking force of the weld.

Problems with the increase of the weld current strength is that it causes bad weld appearance. By bad is meant that the ERW process creates too much expulsion for the electrostatic powder coat to be applied evenly and in small layers.

This paper showed the influence of the ERW parameters on the weld breaking force. Research is in its initial phase but from the given results, weld current strength is successfully identified as the dominant parameter. Taking into consideration that highest breaking force possible is not the ultimate goal of this research some adjustments are needed.

Future work on this research should include more experimental testing with the parameters variation in the smaller increments. Goal of this research would be the control and prediction of the amount of expulsion for creating the process, which will result in strongest weld with satisfactory appearance every time. Additional research must be done to increase process stability thus reducing the deviation in the data. Results given in this paper are expected to be confirmed with additional testing.

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Notice

The paper will be presented at MOTSP 2022 – 13th International Conference Management of Technology – Step to Sustainable Production, which will take place in Primošten/Dalmatia (Croatia) on June 8–10, 2022. The paper will not be published anywhere else.

5 REFERENCES

[1] Pfeifer, M. (2009). Manufacturing Process Considerations. In book: *Materials Enabled Designs*. 115-16010. https://doi.org/1016/B978-0-7506-8287-9.00005-7

[2] Bushell, R. (1951). Resistance welding of cross-wire joints. *Weld. Metal Fabr., 19*(5), 175-178.

[3] Jordan, R. H. (1964). Productivity in multiple cross-wire welding. *Weld. Metal Fabr., 32*(1), 19-26.

[4] Scotchmer, N. (2007). The other resistance process: Cross wire welding. *Welding Journal*, 86(12), 36-39.

[5] Nielsen, C. V., Zhang, W., Bay, N., & Martins, P. A. F. (2021). Cross-wire welding analyzed by experiments and simulations. *Journal of Advanced Joining Processes, 3*, 100039. https://doi.org/10.1016/j.jajp.2020.100039

[6] Du, Z., Wen, S., Wang, J., Yin, C., Yu, D., & Luo, J. (2016). The Review of Powder Coatings. *Journal of Materials Science and Chemical Engineering, 4*, 54-59. https://doi.org/10.4236/msce.2016.43007

[7] Fukumoto, S., Zhou, Y., & Tan, W. (2009). Resistance microwelding. Zhou, Y. (Ed.), *Microjoining and Nanojoining - Woodhead Publishing Series in Welding and Other Joining Technologies*, Woodhead Publishing, 473-499. https://doi.org/10.1533/9781845694043.2.473

[8] Deffenbaugh, J. F. (2003). *Resistance Welding Manual*. 4th revised, Resistance Welder Manufacturers Association, p. 456.

[9] Burster. (2021). Operation manual - Tension and Compression Load Cell Model 8524. https://www.burster.com/fileadmin/user_upload/redaktion/Documents/Products/Manuals/Section_8/BA_8524_EN.pdf (14.01.2022)

[10] Burster. (2021). DigiVision. https://www.burster.com/de/sensorelektronik/digitalanzeiger/p/detail/digivision (14.01.2022)

[11] Kordić, Z. (1987). *Elektrootporno zavarivanje*. Društvo za tehniku zavarivanja Hrvatske. (in Croatian)

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