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PRZEGLĄD SPAWALNICTWA Welding TECHNOLOGY REVIEW

Original Article

Meta-analysis of effect of laser welding parameter on tensile strength of different metals

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Abstract: There are different methods of welding. This different welding is done on a variety of metals. In this paper, meta-analysis is done on laser welding, and studies are done on different metals. 232 research papers were selected based on the title. From these research papers, 47 research papers were selected based on the title. Finally, 16 studies are selected for meta-analysis. This selected data is normalized for the ANOVA test. In ANOVA test found that after welding ultimate tensile strength depend on power and before welding ultimate tensile strength, which verified by correlation plot. A forest plot is also plotted which shows that the data is significant. PCA analysis is done, which shows laser offset welding is irrelevant to welding ultimate tensile strength.

Keywords: beam welding; welding condition; joint strength; weld strength

Introduction

Due to the great difference in thermo-physical properties between copper and stainless steel, welding between them is difficult [1]. Cracks are created after welding copper and stainless steel [2,3]. Therefore, laser welding could be used to weld copper and stainless steel as other welding methods do not give a better result. Laser welding has a relatively thin heat-affected zone, and thin welded area and thus has low distortion [4,5]. However excessive welding speed and excessive power of laser welding are harmful to base metals [6]. Super duplex stainless steel has high strength and is corrosion resistant therefore they are used in gas, oil, and chemical industries [7-9]. Studies show that for dissimilar metals, gas tungsten arc welding (GTAW) and submerged arc welding (SAW) are conventionally used. However, they have low welding speeds due to lower energy density. Therefore, laser welding is done which has high welding speed and high energy density. Beam offset during laser welding also affect joint efficiency. Beam offset is the distance between the position of the laser beam and the weld centre line [10,11]. In the automotive and aerospace industry lightweight materials are used. Aluminium is lightweight and it has low-cost and corrosion resistant. Therefore, scientists are searching for a method of joining aluminium to steel. [12] Titanium is also used in the aerospace industry. Ti1023 have α and β phase in the microstructure. α phase is harder than β phase [13]. High Strength Low Alloy (HSLA) steel is used in vehicles and cranes. TIG welding and MAG welding are used in HSLA steel. TIG welding shows high strength than MAG welding. Lian et al. studied laser-welded HSLA steel joints [14]. Susmita et al. worked on a parametric study and different optimization technique has applied including Genetic Alogrithm (GA), [15] Cricket Alogrithm (CA), [16] Bonobo Optimizer (BO) [17] and Grey Wolf Optimizer (GWO) [18]. Rowe and Liu found problems during underwater arc welding due to high pressure and the water environment. These problems are hydrogen, cracking, and residual stresses [19]. Świerczyńska et al. found that a decrease in diffusible hydrogen content occurs when welding speed decreases or when welding current increases [20]. Balasubramanian et al. studied TC4 which has high efficiency, stability of welding, and deformation resistance [21]. Cam et al. reported that titanium alloy has high laser absorptivity and low thermal conductivity. These properties are advantageous for having a high aspect ratio during Laser Beam Welding [22]. Yunlong et al. worked on underwater laser welding. They utilize a protection nozzle to drain water out from both sides of the sample [23]. Light titanium alloys are used in the aviation field because of their properties which are heat resistance and corrosion resistance [24-26].

Materials and Methods

Data related to the following materials are used. The density of each material used is shown below in Table I.

Table I Material in studies

Material	Density, kg/m³
Copper	8900
Stainless steel	7500
Q235 low-alloy steel	7850
SDSS2507	7800
AA 5052	2680
Ti1023	4650
NiTinol	6450
TC4	4510
AA 5083	2650
AA 6082	2700

Significant Process Parameters

- Laser power. The major factor in the welding process is laser power, which changes depending on the use of the materials during welding. For example, polymers need 5 W laser power, however, ceramics need high power (500 W approximately). Laser power is selected based on process parameters and the magnitude of the laser spot. As the magnitude of the laser spot decreases, its laser energy density increases.
- Welding speed. Laser welding provides greater strength also it has three to ten times faster welding speed as compared to MIG welding. Due to high welding speed, it can join thick materials with less effort.
- Density is a property of materials it defines as mass per unit volume. The SI unit of density is kg/m3. In this research paper density is selected as an independent variable to find a relation with ultimate tensile strength.
- Laser offset (lo) In this paper laser offset effect is also studied. Laser offset is used as the independent variable. Laser offset is used to find the relation with the dependent variable which is the ultimate tensile strength after the welding process.
- Ultimate tensile strength in initial state.
- The maximum stress that material can bear is known as ultimate tensile strength. In brittle materials, yield strength, and ultimate tensile strength are equal. In ductile materials, ultimate tensile strength is higher than yield strength. In this research "buts" is before welding ultimate tensile strength.
- Design of experiments. The design of the experiment is used to find cause-and-effect relationships between variables. In this subject, different variables are analyzed and the relationship between them is found. In this research 232 research papers are selected for the year 2020 based on title. 47 research papers are refined based on the abstract. 16 studies are finally selected based on data in it. Following (Fig. 1) is flow chart of meta-analysis.

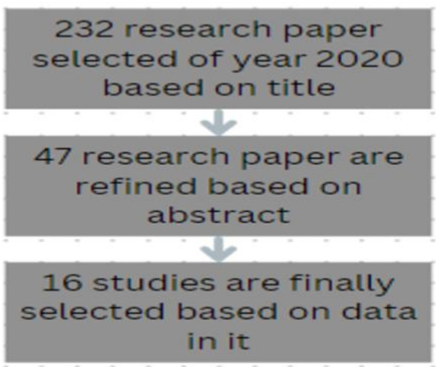

Fig. 1. Flow chart of meta-analysis

Development of Model for Tensile Strength

From research papers data [1-26] is extracted on tensile strength after laser welding at given power and welding speed. Laser offset is also studied. Data about the Ultimate tensile strength before laser welding at room temperature of different metals are also collected Table II.

Table II Selected data of processes, properties of base materials and properties of welded joints from literature [1-26]

Power	Speed	Density	Laser offset (Lo)	UTS, MPa initial state	Welds UTS, MPa
2500	3	8900	0	210	142
2500	3	7500	0	580	128
3000	3	8900	0	210	167
3000	3	7500	0	580	116
6000	1.5	7850	-0.5	785	603
6000	1.5	7850	-0.3	785	603
6000	1.5	7800	0.3	903	571
6000	1.5	7800	0.5	903	779
1200	0.72	2680	0.1	228	120
1200	0.72	2680	0.2	228	129
1200	1.5	4650	0	1100	930
1250	5.2	6450	0	1494	503
2500	1.2	4510	0	1100	842
4100	4	4510	0	1100	661
2200	1.2	2650	0	270	232
2200	1.2	2700	0	270	220

Normalization of data Table III is a major and initial step before processing data for analysis. It is used to make data of uniform scale for easier comparison and analysis.

Table III Normalized data from Table II

No.	Power	Speed	Density	Laser offset (Lo)	UTS, MPa initial state	Welds UTS, MPa
1	0.270833	0.508929	1	0.5	0	0.031941
2	0.270833	0.508929	0.776	0.5	0.288162	0.014742
3	0.375	0.508929	1	0.5	0	0.062654
4	0.375	0.508929	0.776	0.5	0.288162	0
5	1	0.174107	0.832	0	0.447819	0.59828
6	1	0.174107	0.832	0.2	0.447819	0.59828
7	1	0.174107	0.824	0.8	0.53972	0.558968
8	1	0.174107	0.824	1	0.53972	0.814496
9	0	0	0.0048	0.6	0.014019	0.004914
10	0	0	0.0048	0.7	0.014019	0.015971
11	0	0.174107	0.32	0.5	0.693146	1
12	0.010417	1	0.608	0.5	1	0.47543
13	0.270833	0.107143	0.2976	0.5	0.693146	0.891892
14	0.604167	0.732143	0.2976	0.5	0.693146	0.669533
15	0.208333	0.107143	0	0.5	0.046729	0.142506
16	0.208333	0.107143	0.008	0.5	0.046729	0.127764

ANOVA is also known as the analysis of variance. It is used to find whether a null hypothesis is correct or not. Null hypothesis means no relation between studied variables. If the p-value is less than 0.05 it shows that the result is significant. Following Table IV is summary of ANOVA.

Table IV Summary of ANOVA

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Power	1	0.3139	0.3139	324.082	0.0353
Speed	1	0.0009	0.0009	0.958	0.5068
Lo	1	0.0013	0.0013	1.387	0.4482
Density	1	0.0931	0.0931	96.074	0.0647
Buts	1	1.2499	1.2499	1290.32	0.0177
Power: speed	1	0.0582	0.0582	60.036	0.0817
Power: lo	1	0.0434	0.0434	44.795	0.0944
Power: density	1	0.0001	0.0001	0.071	0.8341
Power: buts	1	0.0306	0.0306	31.635	0.112
Speed: density	1	0.0049	0.0049	5.104	0.2653
Speed: buts	1	0.109	0.109	112.555	0.0598
Lo: density	1	0.0187	0.0187	19.327	0.1424
Power: density: buts	1	0.0206	0.0206	21.218	0.1361
Speed: density: buts	1	0.0025	0.0025	2.532	0.3572
Residuals	1	0.001	0.001		

Results and Discussion

Forest plots are used to show the information about the data collected. In the below figure, a forest plot is shown. Heterogeneity lower than 50 percent is acceptable. When heterogeneity is lower than 50 data show less heterogeneity or more homogeneity, also it shows less variance between studies. The P-value is the probability value, when it is less than 0.05, the result is considered as significant. In the below Fig. 2. a confidence interval is not too large, which results in more precision of values.

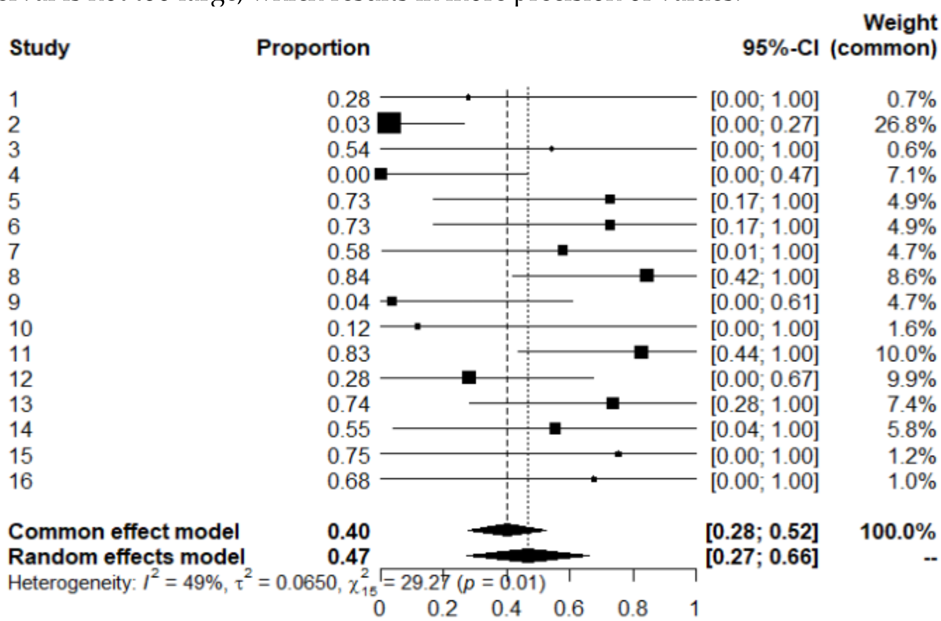

Fig. II Forest Plot

Effect of process parameters on tensile strength

In this research different parameters are studied to find an effect on laser welding ultimate tensile strength (auts). Parameters are laser power, welding speed, laser offset (lo) density, and before welding ultimate tensile strength (buts). From the ANOVA test the following equation is concluded.

$$auts = -0.47-63.22*power -4.8*speed + 0.887*lo + 84.9*density -0.28*buts + 2.7*power*speed+132.3*power*lo-3.9*power*density-2.9*power*buts -4.8*speed*density+7.3*speed*buts-160.1*lo*density-2.46*power*density*buts -2.92*speed*density*buts$$

Correlation plot

To find the intensity of the relationships among different variables correlation plot is used. In the figure below correlation plot Fig. 3. is shown in this study. This graph shows that power depends on the density and after laser welding ultimate tensile strength (auts). Speed depends on the density and before welding ultimate tensile strength (buts). Density depends on power and speed. before welding ultimate tensile strength (buts) depend on power, and speed, and after laser welding ultimate tensile strength (auts). after laser welding ultimate tensile strength (auts) depend on power and before welding ultimate tensile strength (buts).

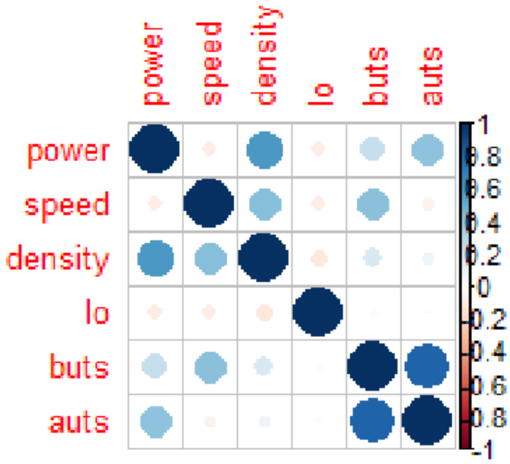

Fig. 3. Correlation Plot

Principal Component Analysis:

A principal component analysis is used to find a degree of correlation between variables. The principal component analysis is used to reduce the dimensions of studies based on the degree of correlation between variables. In the PCA graph for depend on variables, the angle should be less than 90 degrees between two lines. In below figure Fig. 4. shows that all variables depend on one another, except laser offset (lo).

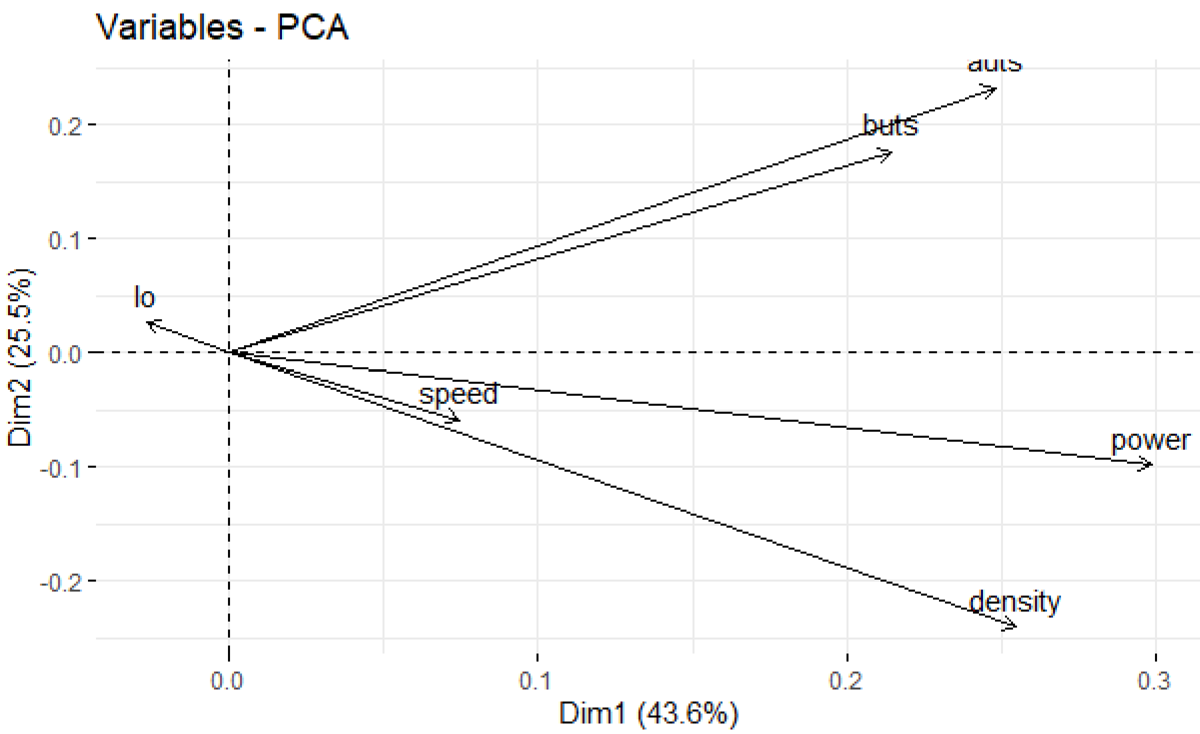

Fig. 4. Principal Component Analysis

Microstructure analysis

Microstructure of base material SDSS2507 form Austenite and Ferrite. Q235 material have ferrite and pearlite in microstructure. Fusion zone of Aluminum contain Continous Fe2Al5 and Acicular Fe4Al13. Laser welded Ti1023 contain elongated and equiaxed β grains in HAZ and FZ respectively. At different laser power, microstructure of HSLA steel contain Acicular ferrite, Martensite/Austenite constituent and Martensite. Microstructure of TC4 contain Martensitic α in Fusion zone, also at HAZ contain primary β grains.

Conclusions

In the above analysis, studies on different metals are done. From the above analysis following conclusion has been made:

- The ANOVA test found that after welding ultimate tensile strength "auts" depend on power and before welding ultimate tensile strength "buts".
- From the forest plot, concluded that heterogeneity is within range, and the results are significant.
- From the correlation plot, found that after welding ultimate tensile strength "auts" changes as power, and before welding ultimate tensile strength "buts" changes, as concluded from the ANOVA test.
- From PCA, concluded that laser offset (lo) does not depend on other given variables.

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Conflicts of Interest: The author declares no conflict of interest.

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