CMSE2022
September 16-19, 2022
Shenzhen, China

CMSE4225

Numerical modelling of the tensile properties of friction stir welding using RSM with experimental design

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The present study aims to optimize friction stir welding (FSW) using statistical tools, thereby improving the mechanical properties of butt welds and achieving the desired butt welds for practical application such as arts of traditional handicraft, and metal sculpture products. The influence of friction stir welding parameters on butt weld was determined by orthogonal array test and variance analysis. The pin length, staying time, tool rotational speed and traverse speed were found to be the highly significant factors of the butt welds. In addition, the response surface method is used to construct the model from the data of the orthogonal array experiment run using the significant factor application by Taguchi design. The experimental results showed that the mechanical properties of butt welds are enhanced by FSW, and the strength of butt welds reached 91%. Furthermore, the fractured properties showed a fine recrystallized grain with fewer defects or imperfections, thereby inproving the workability.

1. Materials and Preparations

(a) (b)

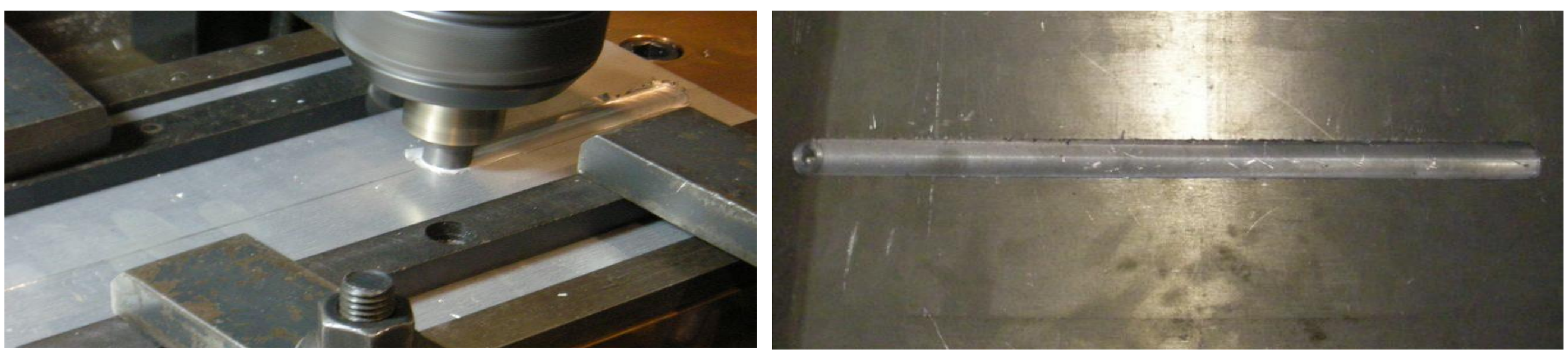

Fig. 1. Typical schematic drawing photographs of equipment for friction stir processing: (a) FSW works by plunging a spinning tool into the joint of two materials and then traversing the rotating tool along the interface; (b) schematic showing the butt welds with the tool stirring the material together and results in a mixture of the two materials.

2. Experimental Results

(a) (b) (c) (d)

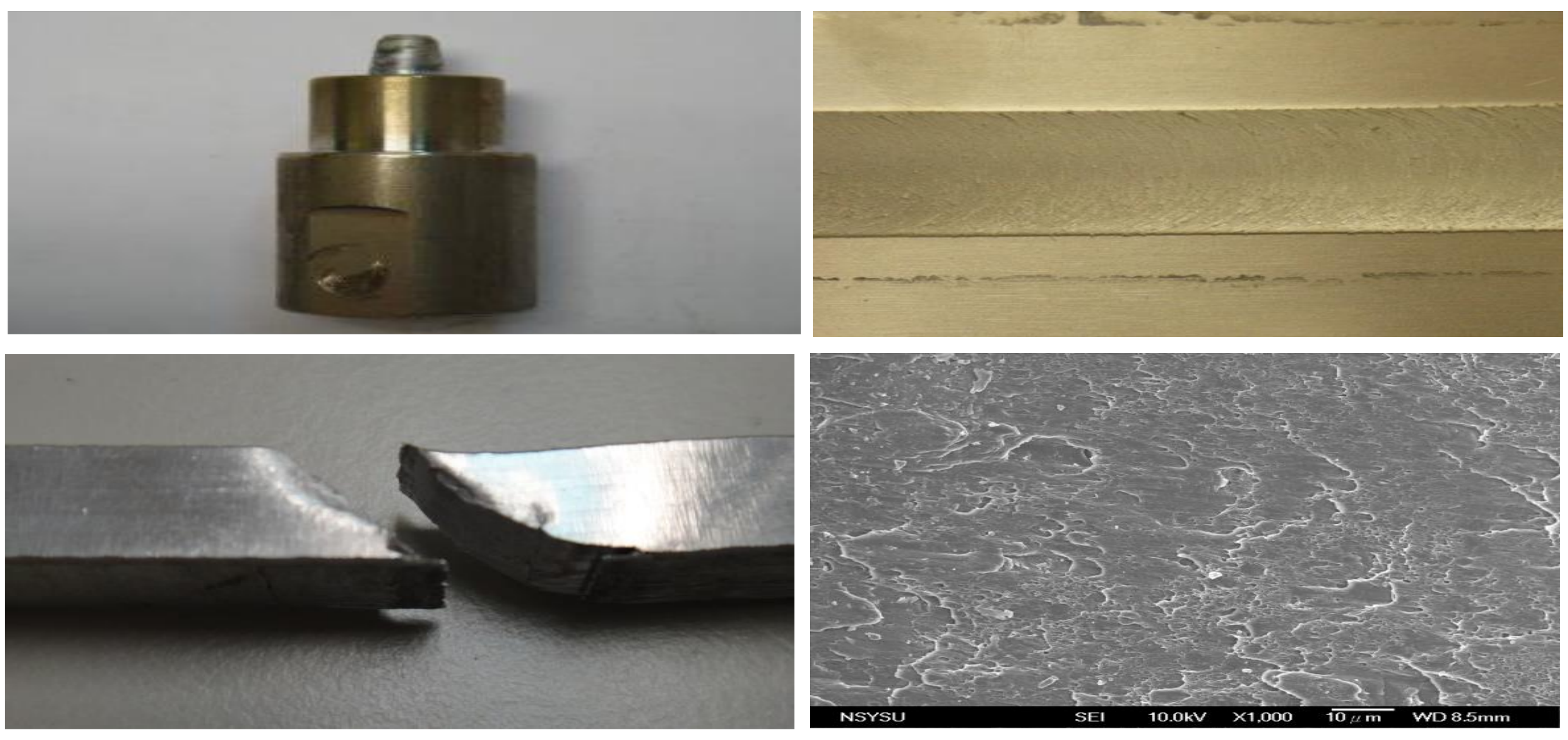

Fig.2. The measured compressive stresses of the pattern of three parameters; a- x-ray diffraction; b- laser power; c- scanning speed; d- stand-off distance.

Table 1. Comparisons for experimental and predicted value of tensile strength(MPa) of linear, interaction and quadratic functions by FSW

No.	Actual	Linear function			Interaction function			Quadratic function		
		Predicted	Error	Percent error	Predicted	Error	Percent error	Predicted	Error	Percent error
1	91.33	120.433	-29.103	31.866	95.655	-4.325	4.736	91.036	0.294	0.322
2	170	136.214	33.786	19.874	134.992	35.008	20.593	168.246	1.754	1.032
3	133.33	139.738	-6.408	4.806	140.345	-7.015	5.261	133.295	0.035	0.026
4	95.33	89.158	6.172	6.474	95.18	0.15	0.157	94.26	1.07	1.122
5	136.33	142.015	-5.685	4.17	131.534	4.796	3.518	138.502	-2.172	1.593
6	189.33	165.212	24.118	12.739	172.164	17.166	9.067	185.136	4.194	2.215
7	101	76.849	24.151	23.912	101.598	-0.598	0.592	104.497	-3.497	3.462
8	147.33	127.211	20.119	13.656	135.481	11.849	8.042	149.161	-1.831	1.243
9	175.33	192.325	-16.995	9.693	197.335	-22.005	12.551	172.202	3.128	1.784
10	97.67	114.657	-16.987	17.392	96.215	1.455	1.49	100.128	-2.458	2.517
11	83.67	91.017	-7.347	8.781	79.928	3.742	4.472	81.168	2.502	2.99
12	200.67	190.711	9.959	4.963	205.503	-4.833	2.408	204.794	-4.124	2.055
13	93.33	105.655	-12.325	13.206	115.713	-22.383	23.983	92.306	1.024	1.097
14	139.33	143.603	-4.273	3.067	149.254	-9.924	7.123	140.024	-0.694	0.498
15	154.67	147.127	7.543	4.877	141.054	13.616	8.803	155.106	-0.436	0.282
16	102.33	102.348	-0.018	0.018	109.88	-7.55	7.378	98.762	3.568	3.487
17	172.33	152.71	19.62	11.385	151.299	21.031	12.204	171.887	0.443	0.257
18	95	141.326	-46.326	48.764	125.181	-30.181	31.769	97.799	-2.799	2.946

CONCLUSIONS

Optimization of the butt joints and utilizing the quadratic model enhanced the tensile properties and supported the yielding of desirable butt welded joints for traditional handicraft repair and large-scale public metal sculpture applications. The fine microstructures of the butt weld were evenly distributed in the welded zone and the grain refinement between the non-welded zone and the welded zone was obvious. Apparently, the surface defects were not observed in the weld zone with a greater bond strength, with the face, toe and root of the weld showing a good welded joint. Also, the micrograph of the tensile-tested specimens associated with a high tensile property was frequently fractured in the diagonal lines of the butt welds; hence, this weld was stronger than that of the other joint in overall tests. This is of great significance to the precision pursuit of metal handicraft and the structural safety of large-scale public metal sculptures. Compared with linear and interactive methods, the quadratic model is better in predicting the tensile strength of butt joints. The predicted abilities of the quadratic model were successful when compared to linear and interaction methods of predicting the tensile strength of the butt joints. Based on the observations from 3D photographs with contour graph, a better compressive tensile strength could be achieved. Clearly, The proposed procedure was validated using the FSW experiments, and the implementation results in RSM based on Taguchi design demonstrated its feasibility and effectiveness in enhancing the mechanical properties by FSW.

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