Investigations on Friction Stir Spot Welding of Dissimilar 3D Printed Parts to Overcome the Bed Size Limitations of FDM-3D Printer

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Keywords:

3D printing, Friction stir spot welding, Unmanned Aerial Vehicle, Printing volume limitation

Introduction:

Additive Manufacturing (AM) or Three-Dimensional Printing (3DP) is an integral part of Industry 4.0 and has widely emerged as a disruptive technology of this era. Compared to the conventional methods, AM squeezes the design-manufacturing cycle time, reducing the production cost by eliminating expensive tooling and fixtures, satisfying the ever-increasing demand of the unpredictable market. Fused Deposition Modeling (FDM) is one such 3D printing technique that is widely accepted because of its inherent advantages such as low-cost machinery, simple fabrication process and ease of operation. However, the FDM technique suffers from several downsides limiting its expansion to its full potential

Among the various drawbacks depicted above, an important limitation that is usually overlooked is its limited build volume, wherein it cannot right away print a part bigger than the bed size. A sensible approach to circumvent this issue could be to section the model and later join/weld the 3D printed parts attaining a larger volume. Welding (Friction Stir, Friction Spin, Friction spot, Ultrasonic, Microwave welding) of 3D printed parts, is one such promising method. However, the welding zone represents the weakest zone in the whole structure reducing the strength. A literature survey conducted in this area revealed that not much work has been done, prompting us to take up the investigation with the objectives framed, discussed in the next section

Objectives:

- To join dissimilar 3D printed parts by FSSW technique.
- To check mechanical properties of the joined 3D printed and FSSW components (Tensile strength and Mode of Fracture.
- Statistical optimisation of the parameters influencing the output by DOE and ANOVA.
- To check the feasibility of applying the optimized parameters to some engineering applications

Methodology:

Most of the commercially available FDM 3D printer comes with a standard size of 240 mm3 volume. This puts a restriction on the size of the final part that can be produced. Hence in the present work, Friction Stir Welding is attempted to overcome this issue. The overall methodology of research work is depicted in Figure 2

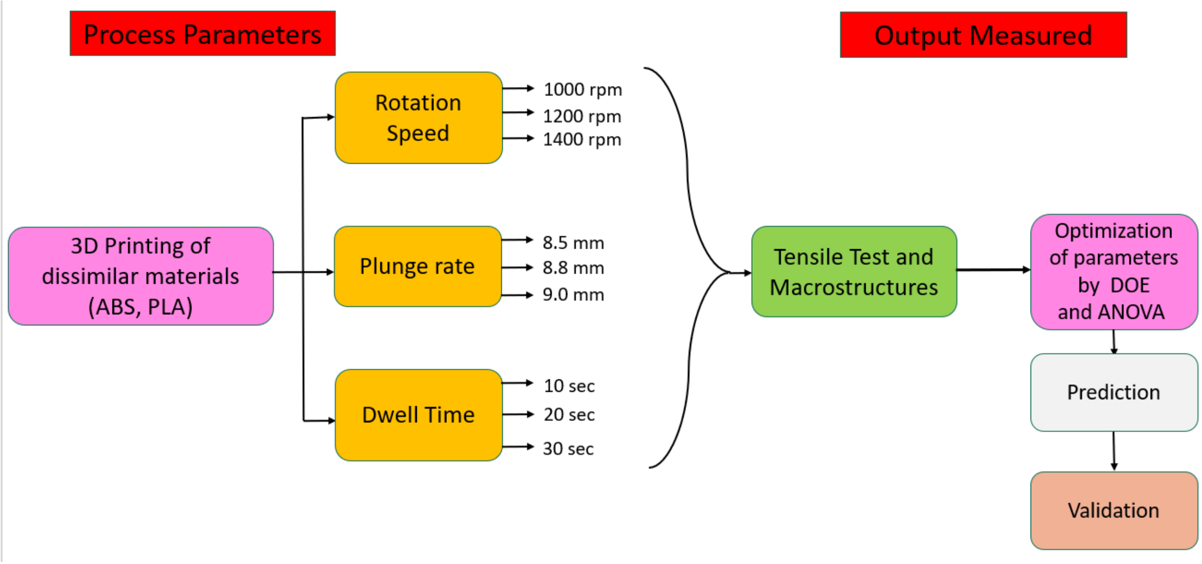


Figure 2: The overall Proposed Methodology of the Investigation

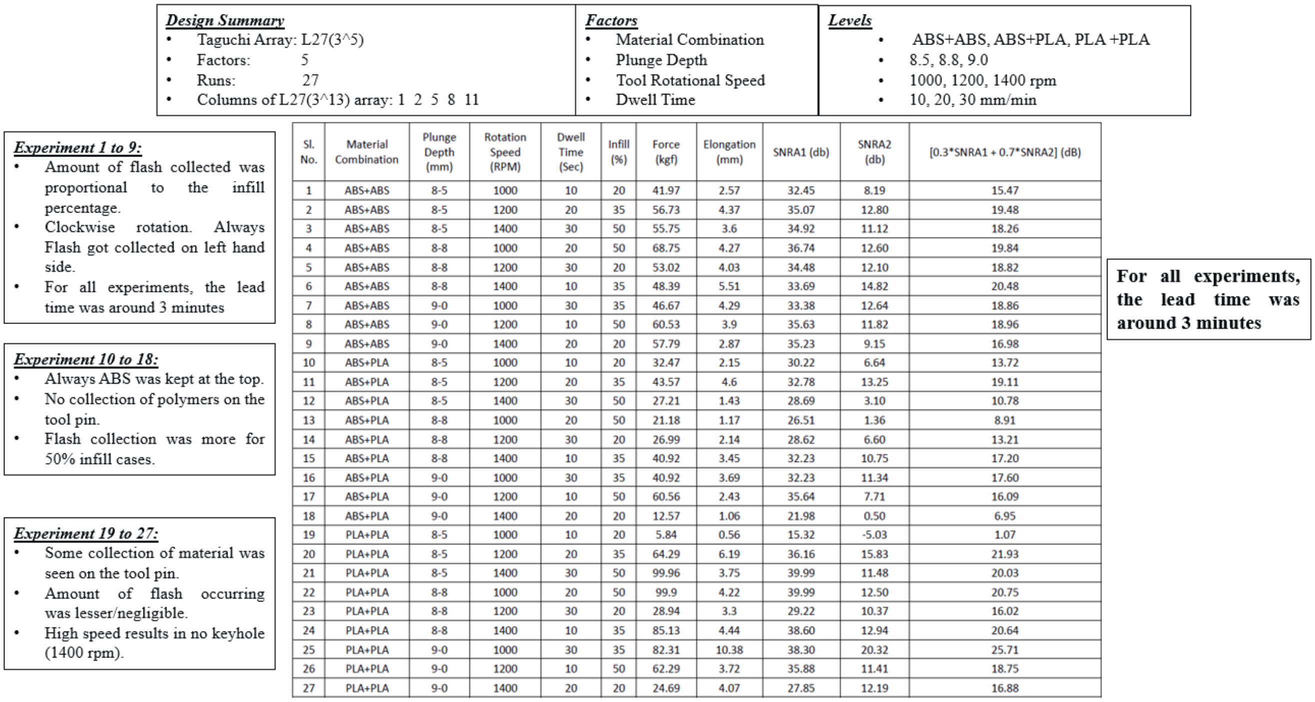
Result and Conclusion:

Table 1 shows the DOE table as per which the experimental trials were conducted. Figure 3 shows the parts before and after FSSW. Figure 4 shows the various Tensile tests conducted on the FSSW parts. Table 2 shows the results obtained employing ANOVA. Figure 6 shows the main effect as well as interaction plots. With the help of various characterization techniques as well as by employing a statistical approach, the optimum parameters affecting the strength of FSSW parts were determined which is presented next. Then in Figure 7 the contribution chart was shown Finally, the optimum parameters obtained from the research which is to be applied to weld the wing of a Clark Y wing section of 400 mm as shown in figure 8. The key findings of the research work conducted are as below:

- Highest strength was obtained for PLA+PLA = 99.96Kgf and optimum process parameters were obtained as shown after the main effect and interaction plots.
- Tensile test results revealed that PLA+PLA material combination showed the highest tensile strength in the graph Force (Kgf) v/s Elongation (mm)
- During the macrostructural study it was found out that the fractures occurred in ABS+ABS were midline fracture, next for ABS+PLA there was delamination and for PLA+PLA it was adherent fracture
- The obtained optimum process parameters and their levels are to be applied to weld

the wing of Clark Y UAV wing of 400mm, i.e., greater than most of the commercially available 3D printers of bed size 230mm.

Hence as a global comment, it could be seen that 3D printed parts can be friction stir spot welded. However, to obtain high strength and more flat components, the parameters have to be selected judiciously. The results obtained from our work is aiming to help manufacturers to obtain larger volume components easily even with smaller 3D printers.



Design Summary
- Taguchi Array: L27(3^5)
- Factors: 5
- Runs: 27
- Columns of L27(3^13) array: 1 2 5 8 11

Factors
- Material Combination
- Plunge Depth
- Tool Rotational Speed
- Dwell Time

Levels
- ABS+ABS, ABS+PLA, PLA +PLA
- 8.5, 8.8, 9.0
- 1000, 1200, 1400 rpm
- 10, 20, 30 mm/min

Experiment 1 to 9:
- Amount of flash collected was proportional to the infill percentage.
- Clockwise rotation. Always Flash got collected on left hand side.
- For all experiments, the lead time was around 3 minutes

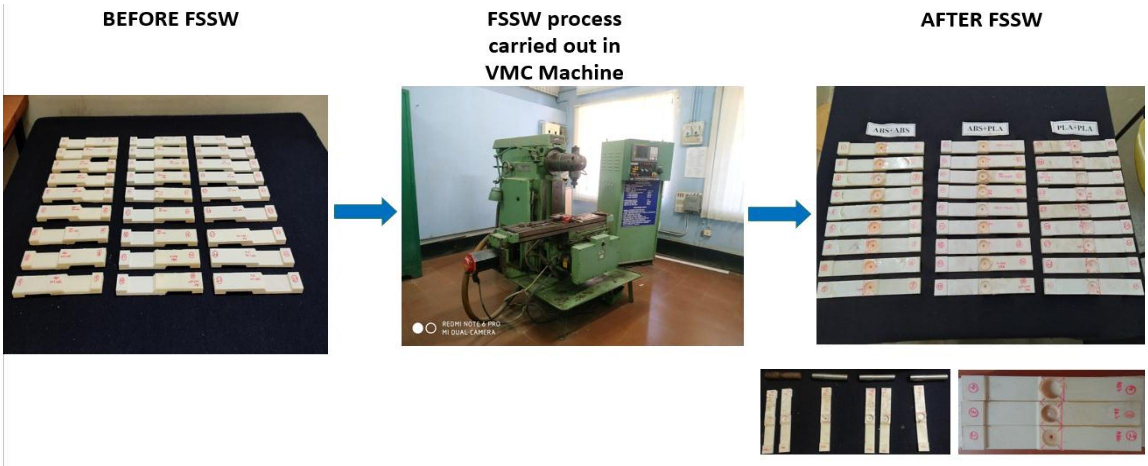
Experiment 10 to 18:
- Always ABS was kept at the top.
- No collection of polymers on the tool pin.
- Flash collection was more for 50% infill cases.

Experiment 19 to 27:
- Some collection of material was seen on the tool pin.
- Amount of flash occurring was lesser/negligible.
- High speed results in no keyhole (1400 rpm).

Sl. No.	Material Combination	Plunge Depth (mm)	Rotation Speed (RPM)	Dwell Time (Sec)	Infill (%)	Force (kgf)	Elongation (mm)	SNRA1 (db)	SNRA2 (db)	[0.3*SNRA1 + 0.7*SNRA2] (dB)
1	ABS+ABS	8-5	1000	10	20	41.97	2.57	32.45	8.19	15.47
2	ABS+ABS	8-5	1200	20	35	56.73	4.37	35.07	12.80	19.48
3	ABS+ABS	8-5	1400	30	50	55.75	3.6	34.92	11.12	18.26
4	ABS+ABS	8-8	1000	20	50	68.75	4.27	36.74	12.60	19.84
5	ABS+ABS	8-8	1200	30	20	53.02	4.03	34.48	12.10	18.82
6	ABS+ABS	8-8	1400	10	35	48.39	5.51	33.69	14.82	20.48
7	ABS+ABS	9-0	1000	30	35	46.67	4.29	33.38	12.64	18.86
8	ABS+ABS	9-0	1200	10	50	60.53	3.9	35.63	11.82	18.96
9	ABS+ABS	9-0	1400	20	20	57.79	2.87	35.23	9.15	16.98
10	ABS+PLA	8-5	1000	10	20	32.47	2.15	30.22	6.64	13.72
11	ABS+PLA	8-5	1200	20	35	43.57	4.6	32.78	13.25	19.11
12	ABS+PLA	8-5	1400	30	50	27.21	1.43	28.69	3.10	10.78
13	ABS+PLA	8-8	1000	20	50	21.18	1.17	26.51	1.36	8.91
14	ABS+PLA	8-8	1200	30	20	26.99	2.14	28.62	6.60	13.21
15	ABS+PLA	8-8	1400	10	35	40.92	3.45	32.23	10.75	17.20
16	ABS+PLA	9-0	1000	30	35	40.92	3.69	32.23	11.34	17.60
17	ABS+PLA	9-0	1200	10	50	60.56	2.43	35.64	7.71	16.09
18	ABS+PLA	9-0	1400	20	20	12.57	1.06	21.98	0.50	6.95
19	PLA+PLA	8-5	1000	10	20	5.84	0.56	15.32	-5.03	1.07
20	PLA+PLA	8-5	1200	20	35	64.29	6.19	36.16	15.83	21.93
21	PLA+PLA	8-5	1400	30	50	99.96	3.75	39.99	11.48	20.03
22	PLA+PLA	8-8	1000	20	50	99.9	4.22	39.99	12.50	20.75
23	PLA+PLA	8-8	1200	30	20	28.94	3.3	29.22	10.37	16.02
24	PLA+PLA	8-8	1400	10	35	85.13	4.44	38.60	12.94	20.64
25	PLA+PLA	9-0	1000	30	35	82.31	10.38	38.30	20.32	25.71
26	PLA+PLA	9-0	1200	10	50	62.29	3.72	35.88	11.41	18.75
27	PLA+PLA	9-0	1400	20	20	24.69	4.07	27.85	12.19	16.88

For all experiments, the lead time was around 3 minutes

Table 1. DOE Table



Results obtained when PLA is on top during ABS+PLA

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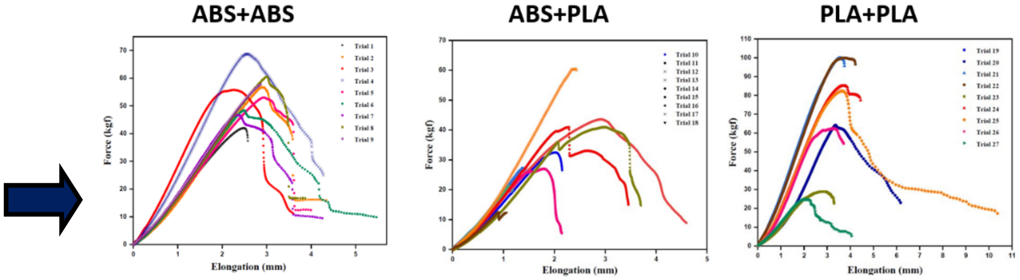
Figure 3. FSSW process of all 27 specimens conducted in VMC Machine



Full Specimen Strength (kgf)	After Tests (kgf)	Joint Efficiency (%)
ABS = 117.3	ABS+ABS = 68.75	ABS+ABS = 0.58
PLA = 99.7	ABS+PLA = 60.56	ABS+PLA = 0.51
	PLA+PLA = 99.96	PLA+PLA = 1.00

Figure 4. Tensile Tests conducted on all 27 specimens

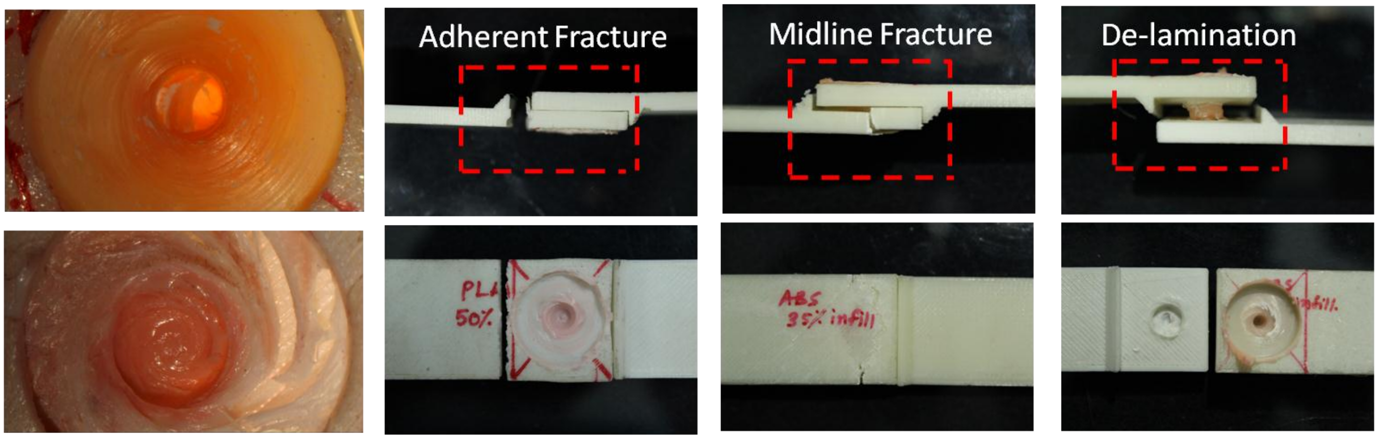


Figure 5. Macrostructural Analysis of the Fractured Specimens

(Considering 30% to Force and 70% to Elongation)

SOURCE	DF	Adj SS	Adj MS	F - Value	P - Value	% Contribution
Material Combination	2	125.64	62.81	3.71	0.04	18.75
Plunge Depth(mm)	2	20.15	10.07	0.60	0.56	3.0
Rotation Speed (rpm)	2	24.35	12.17	0.72	0.50	3.63
Dwell Time (sec)	2	15.92	7.96	0.47	0.63	2.37
Infill (%)	2	213.31	106.65	6.30	0.01	31.83
Error	16	270.69	16.91			40.39
Total	26	670.06				99.97

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.11	59.60%	34.35%	0.00%

Table 2. ANOVA table after analysis

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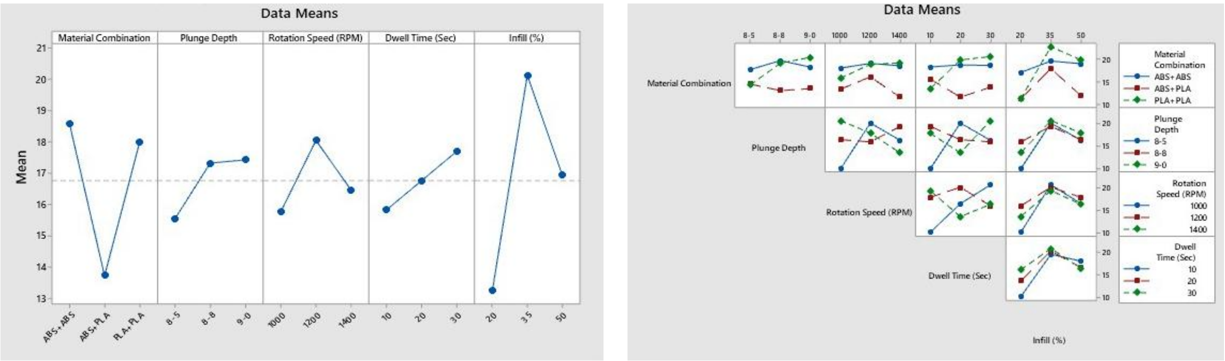

Figure 6. Main effect and Interaction plots

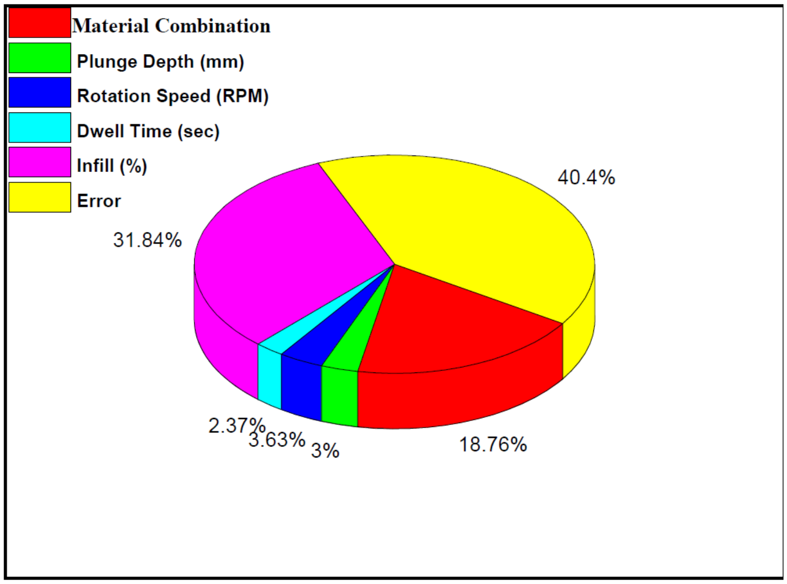

Figure 7. Contribution Chart

Optimum Process Parameters:

- **Infill – 35%**
- **Material Combination – ABS+ABS**
- **Rotation Speed (rpm) - 1200 rpm**
- **Plunge Depth (mm) - 9 mm**
- **Dwell Time (sec) - 30 sec**

Scope for Future Work

The future of 3D printing is very bright and can be more promising, provided it can overcome the bed size limitation. Printing smaller parts and then joining them by FSSW seems to be a very economical and meaningful solution to circumvent this issue. From our work, it can be seen that 3D printing combined with welding methods like FSSW will become a more common method in the future overcoming the bed size limitation. This will bring down the cost as well as the energy consumption, making the technology more acceptable among the manufacturing leaders. This can be an advantageous fact particularly for aerospace and automotive industries

Clark Y Wing on which the research work is to be applied