Investigations on Microwave-Assisted Joining of FDM 3D Printed Parts to Overcome its Bed Size Limitation Applied to UAV Wings

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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. This is due to the outstanding design freedom it offers at an extremely lower cost. However, despite the advantages that FDM-3DP is offering, there are several downsides the technology faces, limiting its expansion to its full potential (Figure 1).

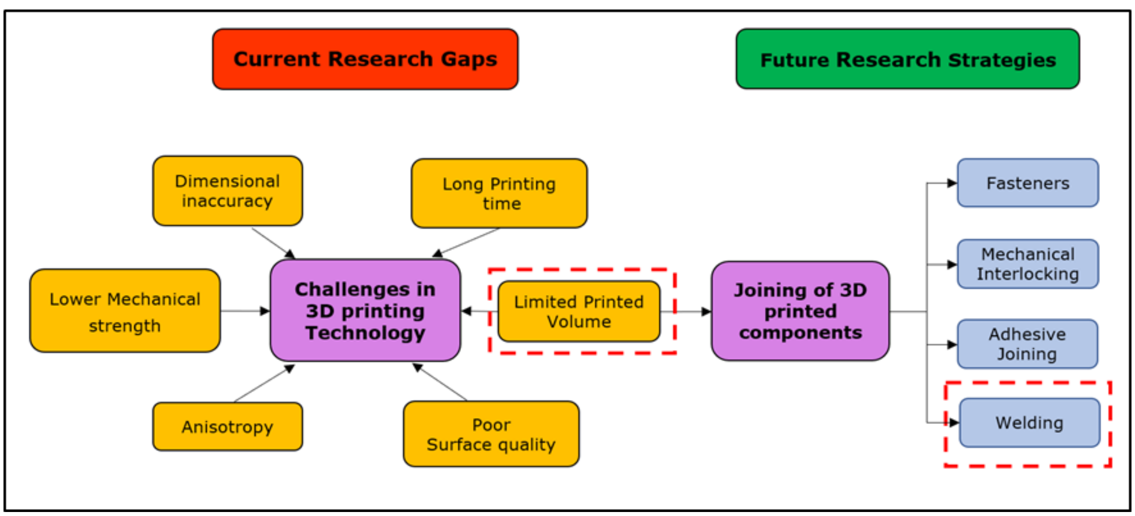


Figure1: Challenges and the driving force in FDM-3D Printing technology

The limited bed size of a commercially available 3D printer is a limitation that holds its acceptability by the manufacturing business leaders. Due to this limited bed size, it is difficult to fabricate a larger industrial component. While a bigger bed size printer costs more and the rate of successful print is also less due to the warpages and thermal issues. Hence, to circumvent this issue, joining of the 3D printed parts by adhesives, welding, fastening, and interlocking could be attempted, thereby attaining a larger volume of the 3D printed component. 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:

- 3D printing of dissimilar polymers (ABS & PLA) by FDM Technology and joining them by Microwave Welding technique employing different ICP's.
- Evaluating the performance of the joints in terms of mechanical properties (tensile, flexural) and macrostructural analysis.
- Statistical optimization of the process parameters involved in the welding technique using DOE/ ANOVA to obtain the best results.
- Applying the optimized results to microwave weld the wingspan of a UAV wing

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, Microwave Welding is attempted to overcome this issue. The overall methodology of research work is depicted in Figure 2

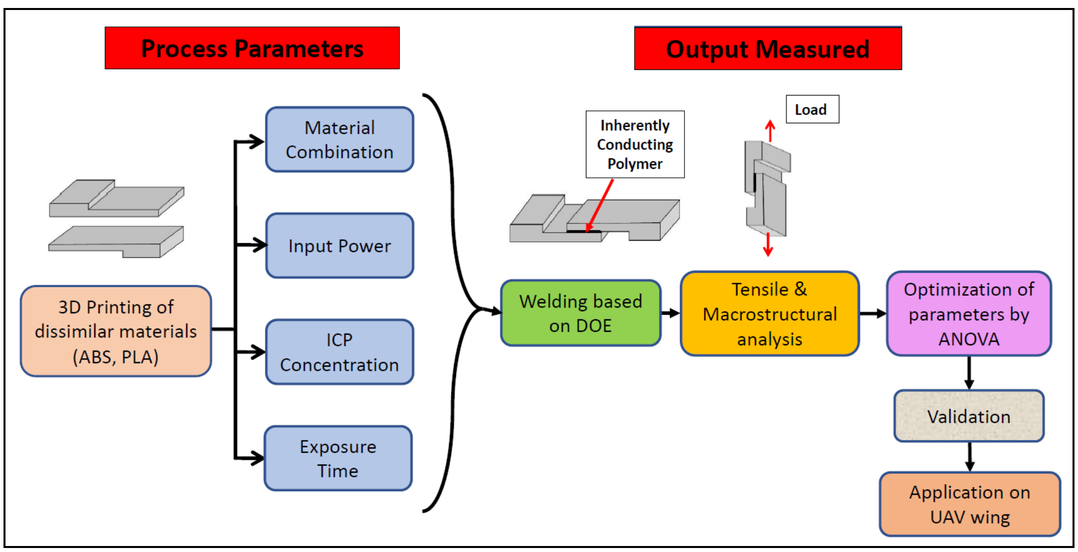


Figure 2: The overall Proposed Methodology of the Investigation

Result and Conclusion:

The below table shows the DOE table for which the experimental trials for microwave welding were conducted, tested, and analyzed. Two input parameters were chosen from 3D printing i.e., material combination & infill percentage; while the other three parameters were chosen from the microwave welding process i.e., power, susceptor weight, and dead weight. Figure 3 shows the parts before and after Microwave Welding. Figure 4 shows the force vs elongation graphs for the tensile tests conducted on the Microwave Welding parts. Table 2 shows the results obtained employing ANOVA, figure 5 shows the contribution chart. Figure 6 shows the main effect plot & figure 7 shows the interaction plots. With the help of various characterization techniques as well as by employing a statistical approach, the optimum parameters affecting the strength of Microwave Welding parts were determined which is presented in figure 8. Lastly, figure 9 shows the application of microwave welding to fabricate the body of a drone**.**

Inputs						Outputs		DOE Analysis		
Sl. No.	Material Combination	Power (W)	Susceptor Weight (grams)	Dead Weight (grams)	Infill Percentage (%)	Tensile strength (kgf)	Elongation (mm)	SNRA 1	SNRA 2	Combined Objective Function [0.5*SNRA1 + 0.5*SNRA2] (dB)
1	ABS+ABS	600	0.2	400	20	86.09	3.39	38.70	10.60	24.65
2	ABS+ABS	600	0.25	800	35	73.89	2.87	37.37	9.16	23.26
3	ABS+ABS	600	0.3	1200	50	83.39	2.78	38.42	8.88	23.65
4	ABS+ABS	800	0.2	800	50	105.09	3.48	40.43	10.83	25.63
5	ABS+ABS	800	0.25	1200	20	94.91	3.76	39.55	11.50	25.52
6	ABS+ABS	800	0.3	400	35	99.95	3.98	40.00	12.00	26.00
7	ABS+ABS	1000	0.2	1200	35	79.4	3.95	38.00	11.93	24.96
8	ABS+ABS	1000	0.25	400	50	116.75	3.7	41.35	11.36	26.35
9	ABS+ABS	1000	0.3	800	20	95.28	5.28	39.58	14.45	27.02
10	ABS+PLA	600	0.2	400	20	58.49	2.27	35.34	7.12	21.23
11	ABS+PLA	600	0.25	800	35	39.25	2.21	31.88	6.89	19.38
12	ABS+PLA	600	0.3	1200	50	51.81	2.02	34.29	6.11	20.20
13	ABS+PLA	800	0.2	800	50	56.96	2.2	35.11	6.85	20.98
14	ABS+PLA	800	0.25	1200	20	21.74	1.33	26.75	2.48	14.61
15	ABS+PLA	800	0.3	400	35	89.49	3.24	39.04	10.21	24.62
16	ABS+PLA	1000	0.2	1200	35	69.35	2.79	36.82	8.91	22.87
17	ABS+PLA	1000	0.25	400	50	74.47	2.16	37.44	6.69	22.06
18	ABS+PLA	1000	0.3	800	20	70.17	2.47	36.92	7.85	22.39
19	PLA+PLA	600	0.2	400	20	62.64	2.91	35.94	9.28	22.61
20	PLA+PLA	600	0.25	800	35	70.95	2.3	37.02	7.23	22.13
21	PLA+PLA	600	0.3	1200	50	28.7	1.67	29.16	4.45	16.81
22	PLA+PLA	800	0.2	800	50	83.81	2.98	38.47	9.48	23.98
23	PLA+PLA	800	0.25	1200	20	73.05	2.95	37.27	9.40	23.33
24	PLA+PLA	800	0.3	400	35	99.22	3.76	39.93	11.50	25.72
25	PLA+PLA	1000	0.2	1200	35	89.16	3.76	39.00	11.50	25.25
26	PLA+PLA	1000	0.25	400	50	78.95	2.7	37.95	8.63	23.29
27	PLA+PLA	1000	0.3	800	20	64.79	2.91	36.23	9.28	22.75

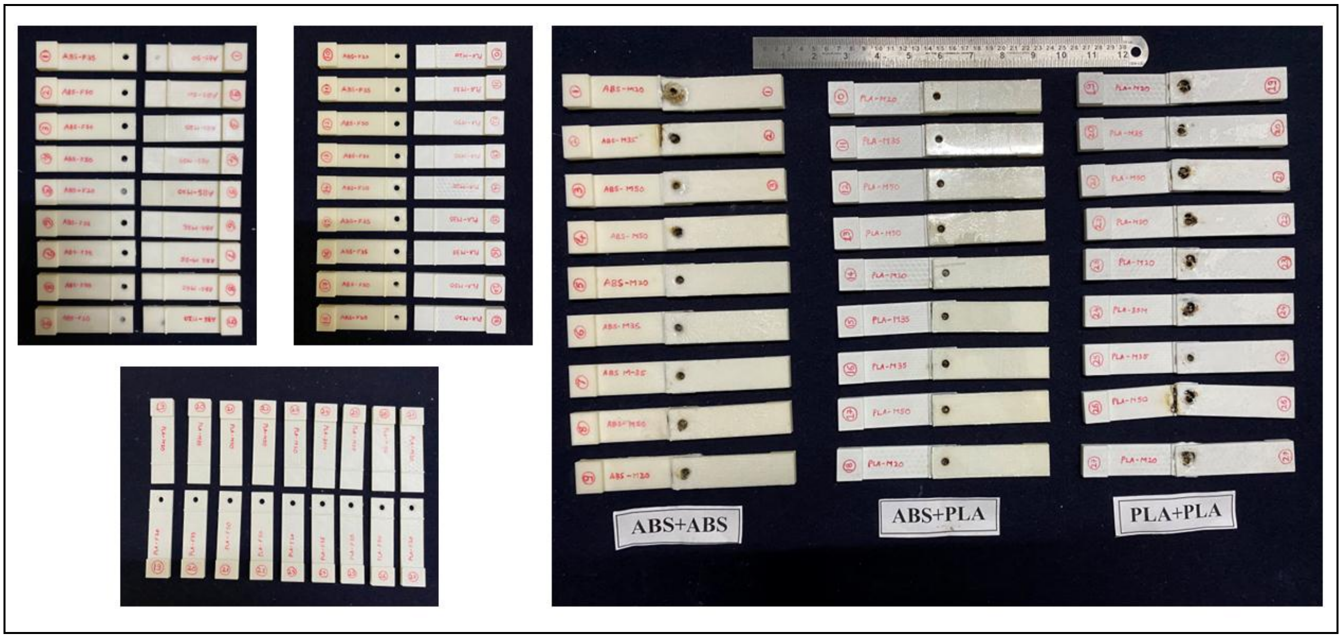
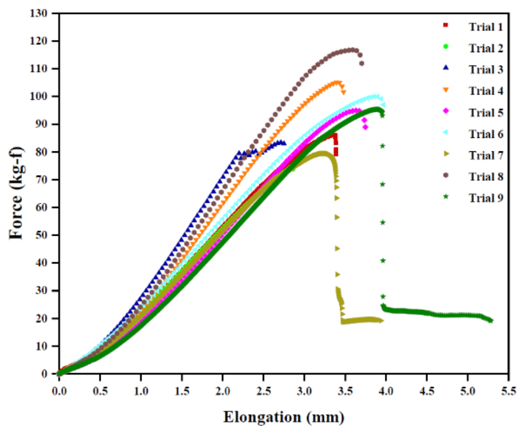
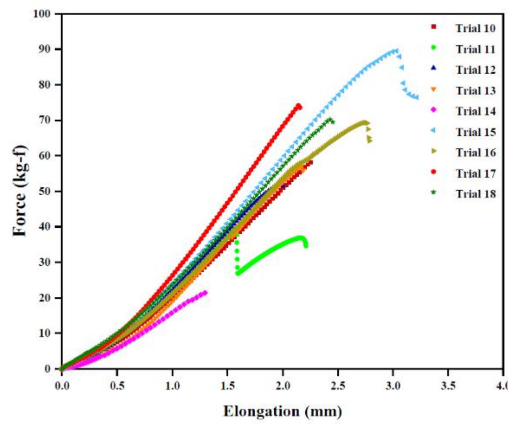


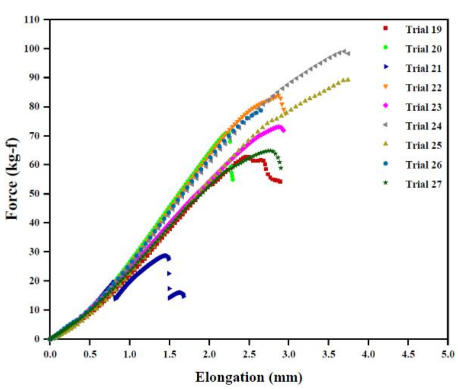
Figure 3: Microwave welded specimens of different material combinations



ABS+ABS



PLA+PLA



ABS+PLA

Figure 4: Tensile Test Plots

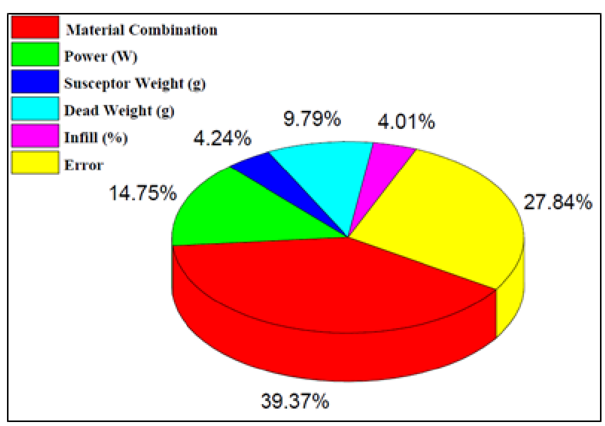


Figure 5: Contribution Chart

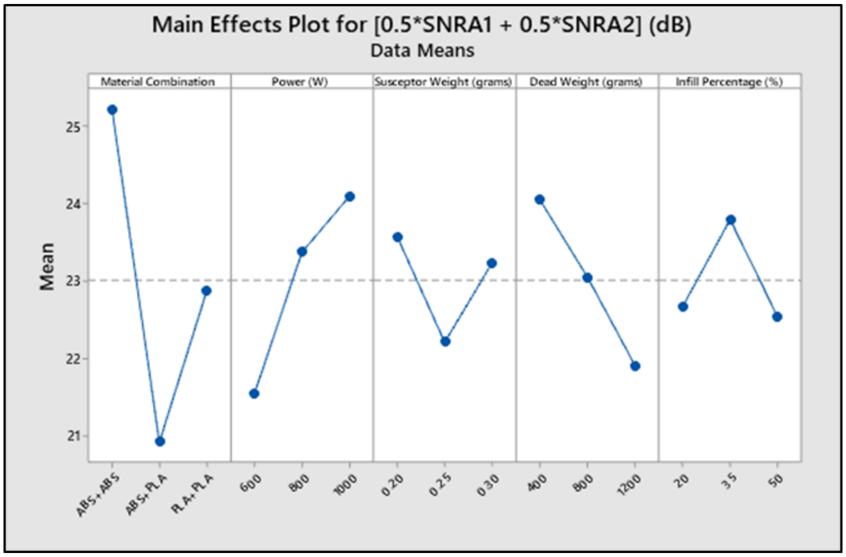


Figure 6: Main Effect Plot for [0.5*SNRA1 + 0.5*SNRA2] (dB)

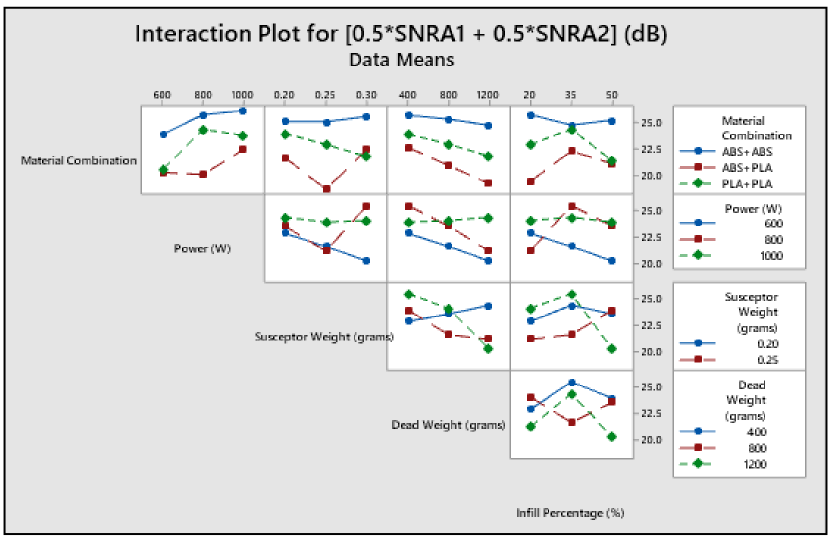


Figure 7: Interaction Plot for [0.5*SNRA1 + 0.5*SNRA2] (dB)

Optimum Process Parameters:	1. **Material Combination – ABS+ABS** 2. **Power (W) – 1000 W** 3. **Dead Weight (grams) – 400 g** 4. **Susceptor Weight (grams) - 0.20 g** 5. **Infill Percentage (%) – 35%**

Figure 8: Optimum Process Parameters

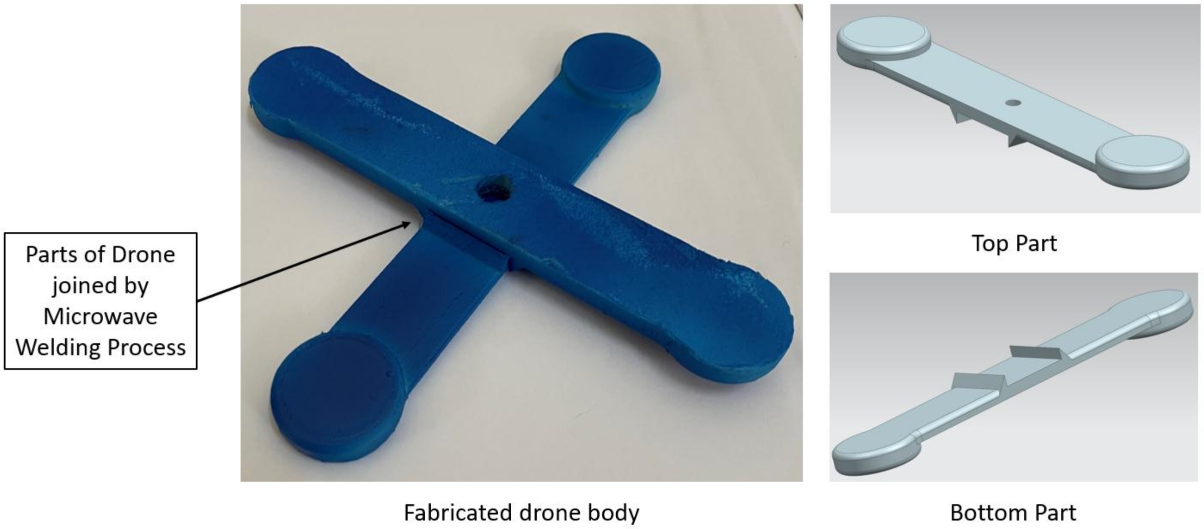


Figure 9: Application on the drone body

Hence as a global comment, it could be seen that 3D printed parts can be Microwave Welded. However, to obtain high-strength 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.

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 MICROWAVE WELDING 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 microwave welding will become a more common method in the future for 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.

In addition to solving the problem of limited bed size, microwave welding can also be applied to repair broken 3D printed plastic components. By applying the susceptor at the location where the component has split, a weld can be formed in order to rejoin the component using the microwave welding process. This is advantageous as microwave welding is quick, and affordable option in this particular case, and further study into its practicality can be conducted.