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1. Problem Statement and Objective

- Dual Laser Adjustable Mode Beam (DLAMB) is a new laser welding technology whose parameter–alloy influence on fusion geometry, and a ready-to-use predictive correlation, remain unresolved.
- This work aims to quantify DLAMB parameter and alloy effects on fusion geometry for SS 304, Ti6Al4V, and Inconel 718, and derive predictive equations and process maps to precisely predict melt-pool shape.

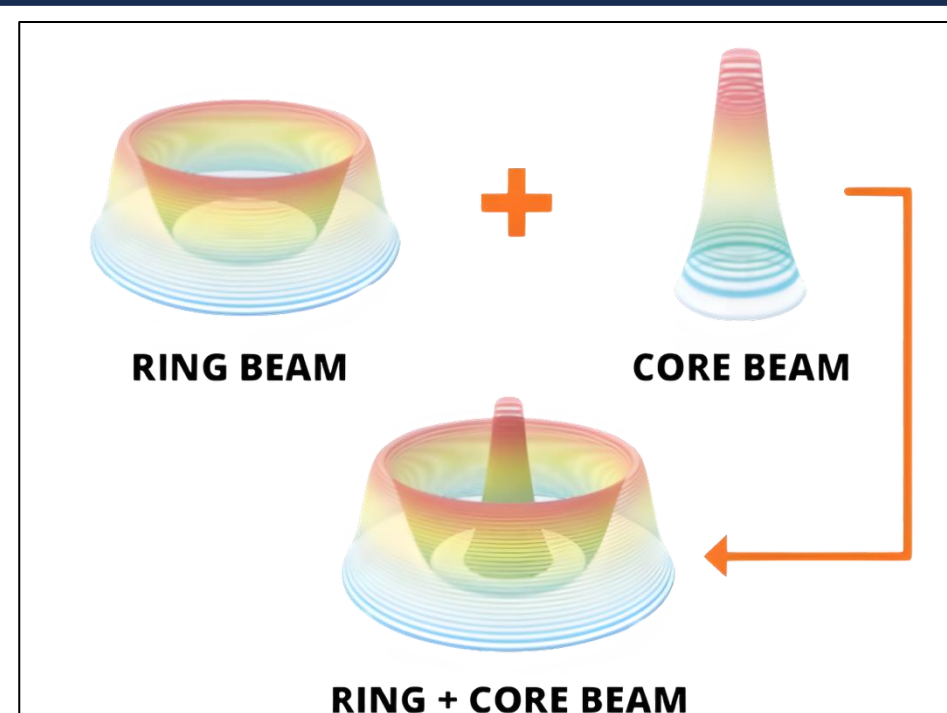


Figure 1. DLAMB configuration.

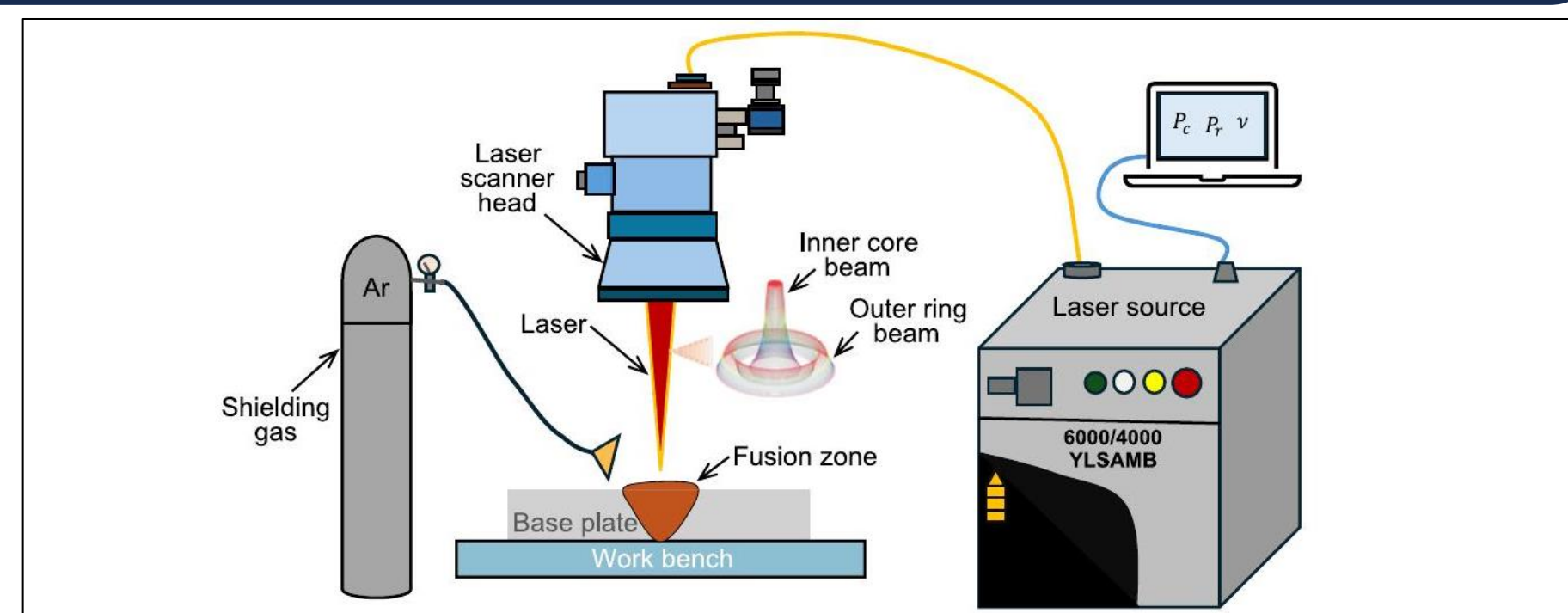


Figure 2. Schematic of the DLAMB welding experimental setup.

2. Materials and Methods

Material: SS 304, Ti6Al4V, and Inconel 718 plates (6.9 mm thickness)

- DLAMB configuration:** core beam (≤ 6 kW) + ring beam (≤ 4 kW), 1070 nm, 10 kW system.
- Test matrix:** 24 tests per alloy (72 total), varying core power, ring power, and welding speed (50–150 mm/s). Sample test set shown in Table 1.
- Sample preparation:** Waterjet cut, mount, grind, polish, alloy-specific etch; depth/width measured by confocal microscopy.
- Analysis:** supervised ML linear regression (5 causative variables); ablation and sensitivity analysis to rank variable importance.

Table 1. DLAMB welding process parameters

Test	Core laser power, W	Ring laser power, W	Welding speed, mm/s	Test	Core laser power, W	Ring laser power, W	Welding speed, mm/s
1	1200	0	50	13	500	700	100
2	800	400	50	14	400	800	100
3	600	600	50	15	0	1200	100
4	400	800	50	16	1200	0	150
5	3000	0	50	17	800	400	150
6	2000	1000	50	18	700	500	150
7	1000	2000	50	19	600	600	150
8	0	3000	50	20	500	700	150
9	1200	0	100	21	400	800	150
10	800	400	100	22	900	0	150
11	700	500	100	23	800	0	150
12	600	600	100	24	700	0	150

3. Results and Discussion

- Laser power distribution:** Shifting power from core to ring beam shifts the fusion mode from deep, narrow keyhole to wide, shallow conduction (Figure 3).
- Welding speed:** Lower speed increases heat input, giving a wider, deeper fusion zone; higher speed gives a narrower, shallower zone (Figure 4).
- Alloy properties:** Under identical conditions, Inconel 718 gives the deepest melt pool (lowest solidus temperature) and Ti6Al4V the widest (lowest density).
- Independent variables:** The five causative variables show weak pairwise correlation, supporting linear regression (Figure 4).
- Predictive equations:** The derived depth/width equations achieved $R^2 = 0.98$, with test errors of 2.6% and 6.3% of maximum measured values (Figure 5); Equations (1) and (2) predict melt-pool depth and width.
- Process maps:** The equations generate process maps for SS304, Ti6Al4V, and Inconel 718 across the DLAMB parameter space (Figure 6).
- Hierarchical importance:** Core laser power is most sensitive for depth; ring laser power and solidus temperature dominate width (Figures 7–8).

Melt pool depth (D, unit meter) :

$$D = 9.97 \times 10^{-7} P_c + 4.54 \times 10^{-7} P_r - 3.3410^{-3} v - 2.6610^{-8} T_s - 22.7\alpha \quad (1)$$

Melt pool width (W, unit meter) :

$$W = 4.32 \times 10^{-7} P_c + 4.8 \times 10^{-7} P_r - 4.91 \times 10^{-3} v - 1.01 \times 10^{-8} T_s - 202\alpha \quad (2)$$

Where, P_c – Core power, P_r – Ring power, v – Welding speed, T_s – Solidus temperature, α – Thermal diffusivity

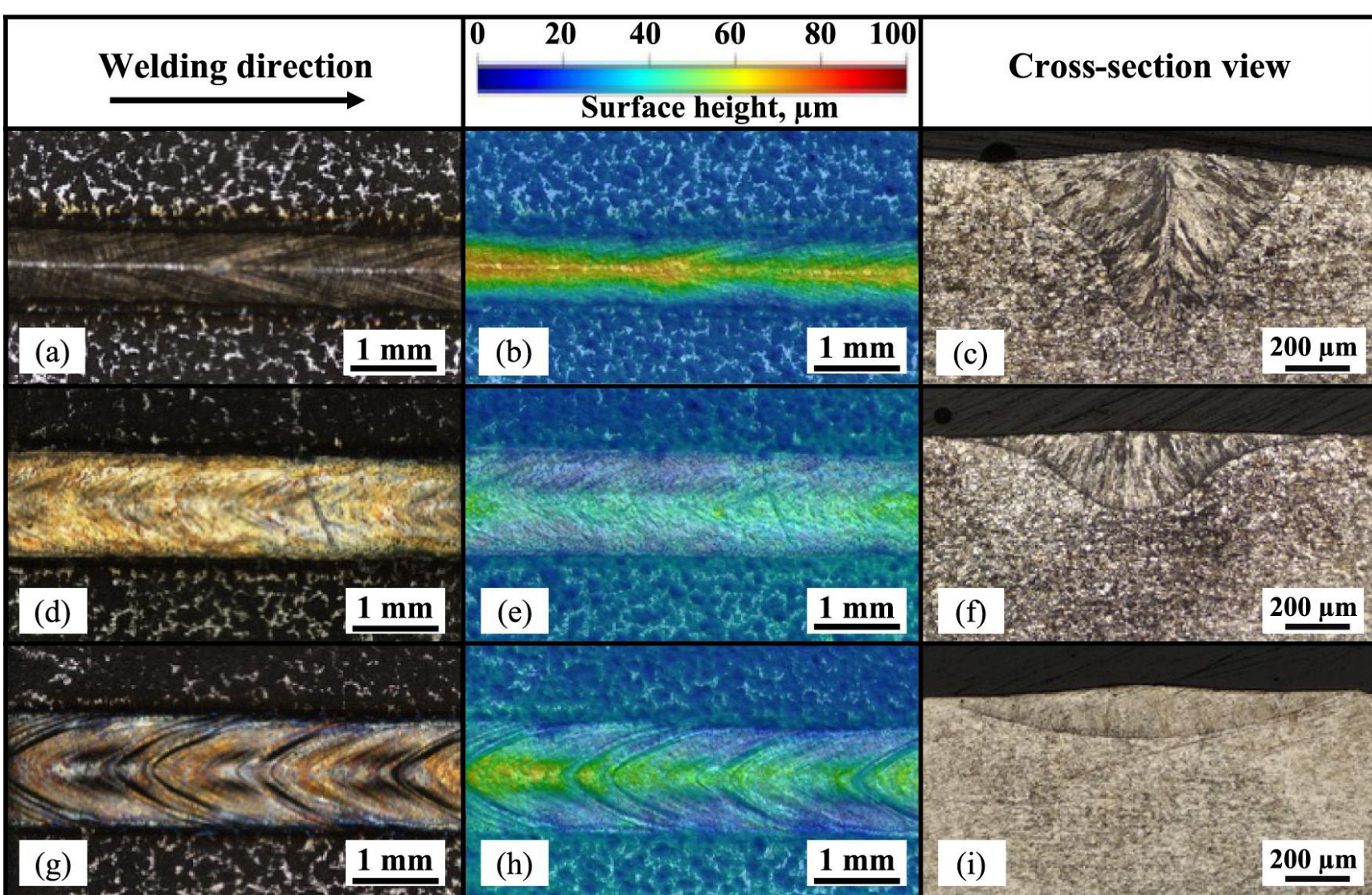


Figure 3. Core/ring power effect on SS304 (Tests 9,14,15).

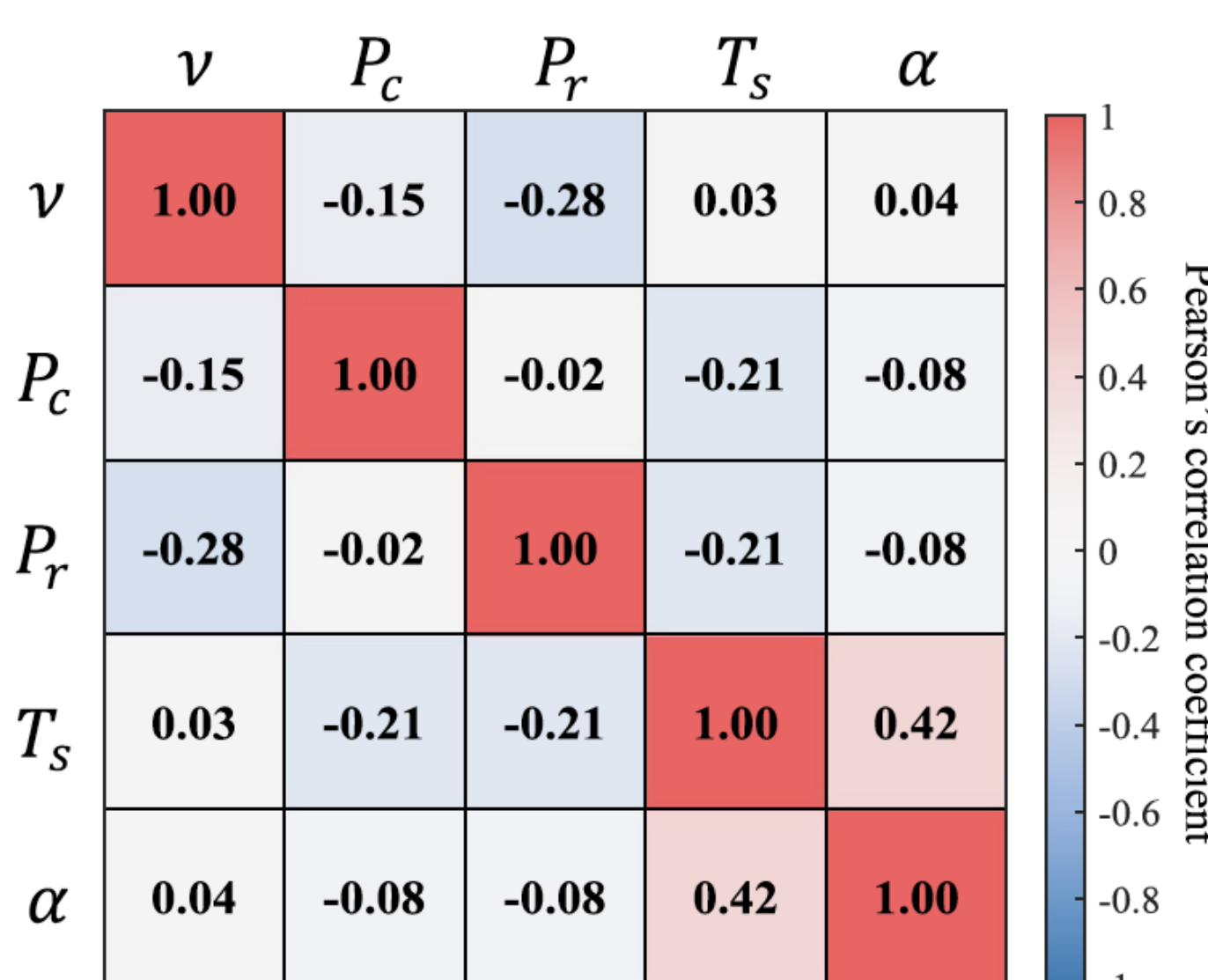


Figure 4. Pearson correlation matrix of the five variables.

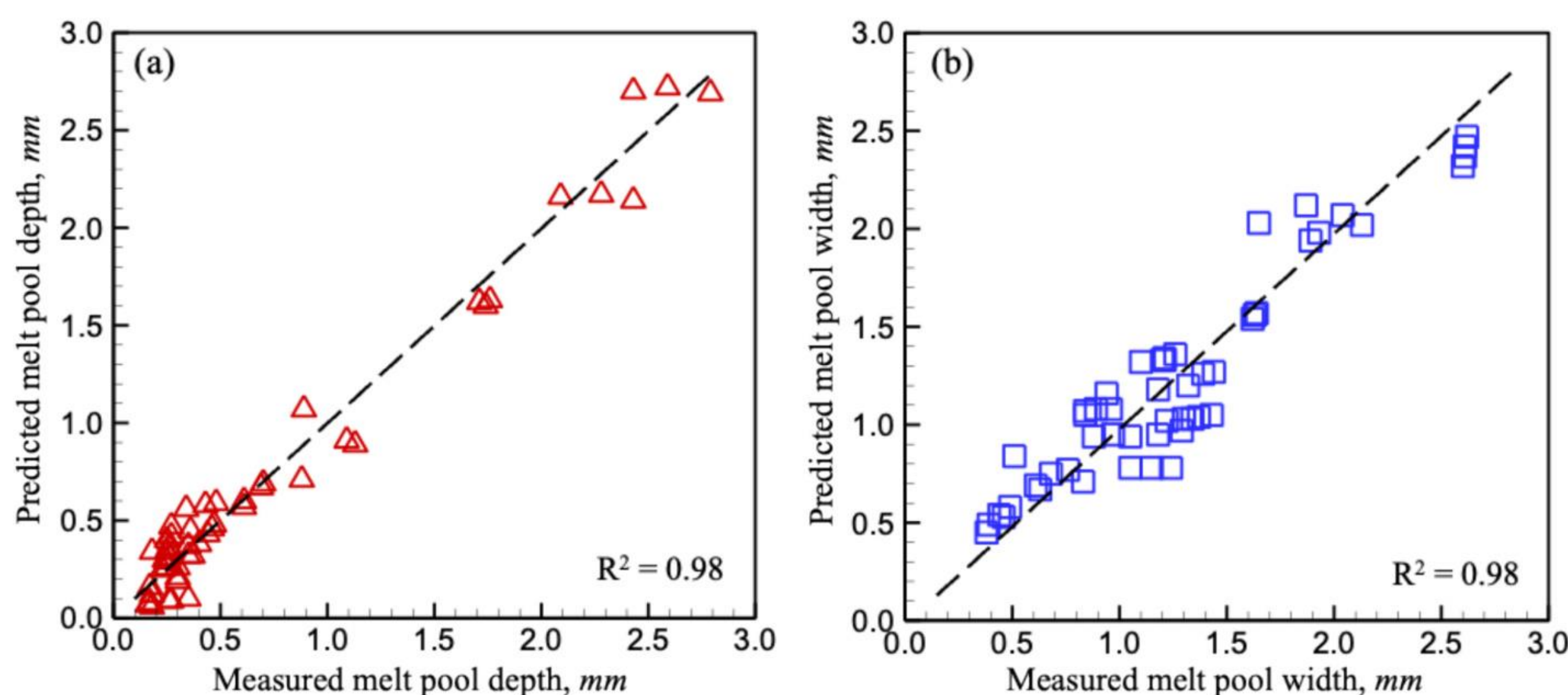


Figure 5. Predicted vs. measured melt pool (a) depth and (b) width $R^2 = 0.98$.

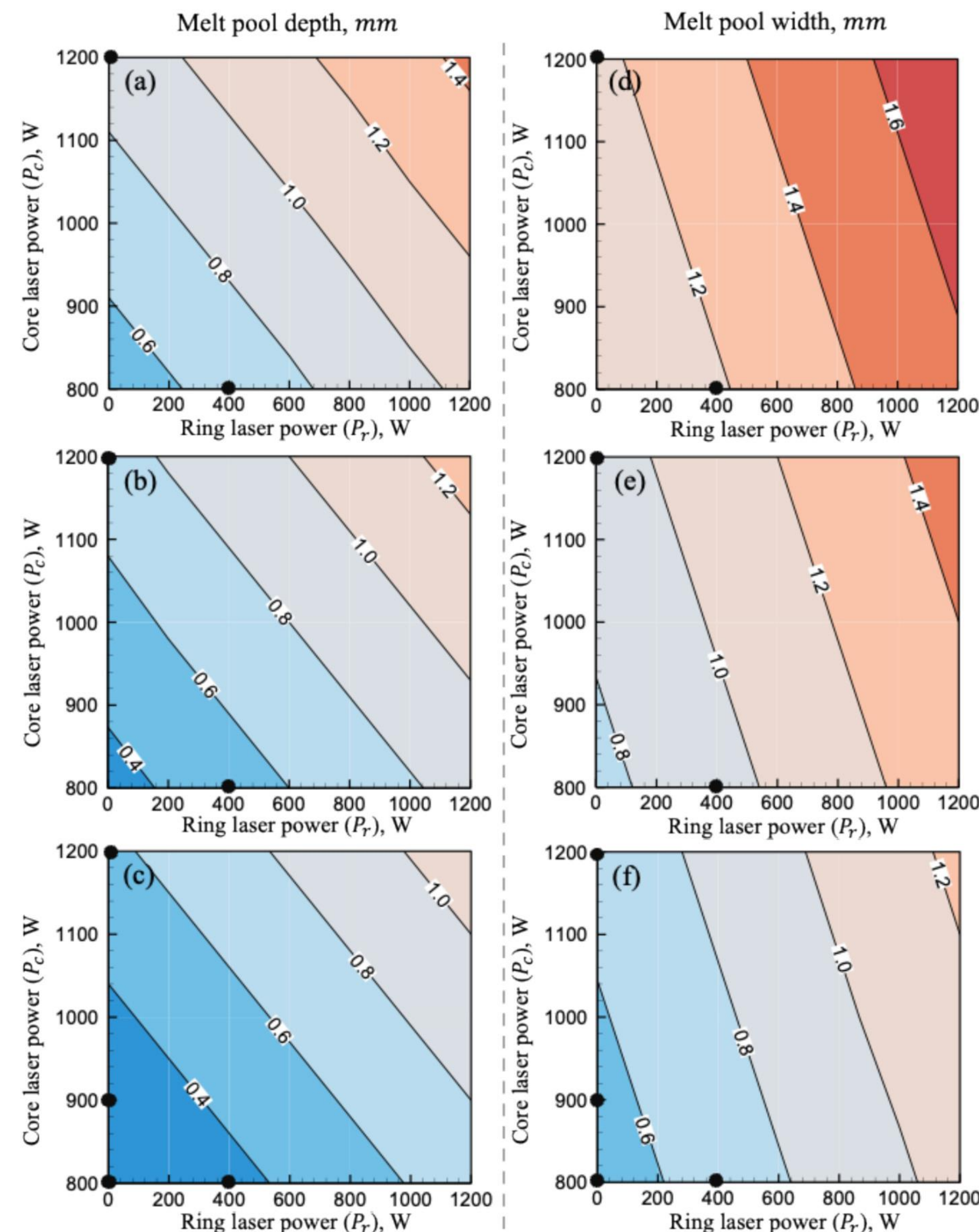


Figure 6. Process maps for SS304; (a,d) $\rightarrow$ 50 mm/s; (b,e) $\rightarrow$ 100 mm/s; (c,f) $\rightarrow$ 150mm/s

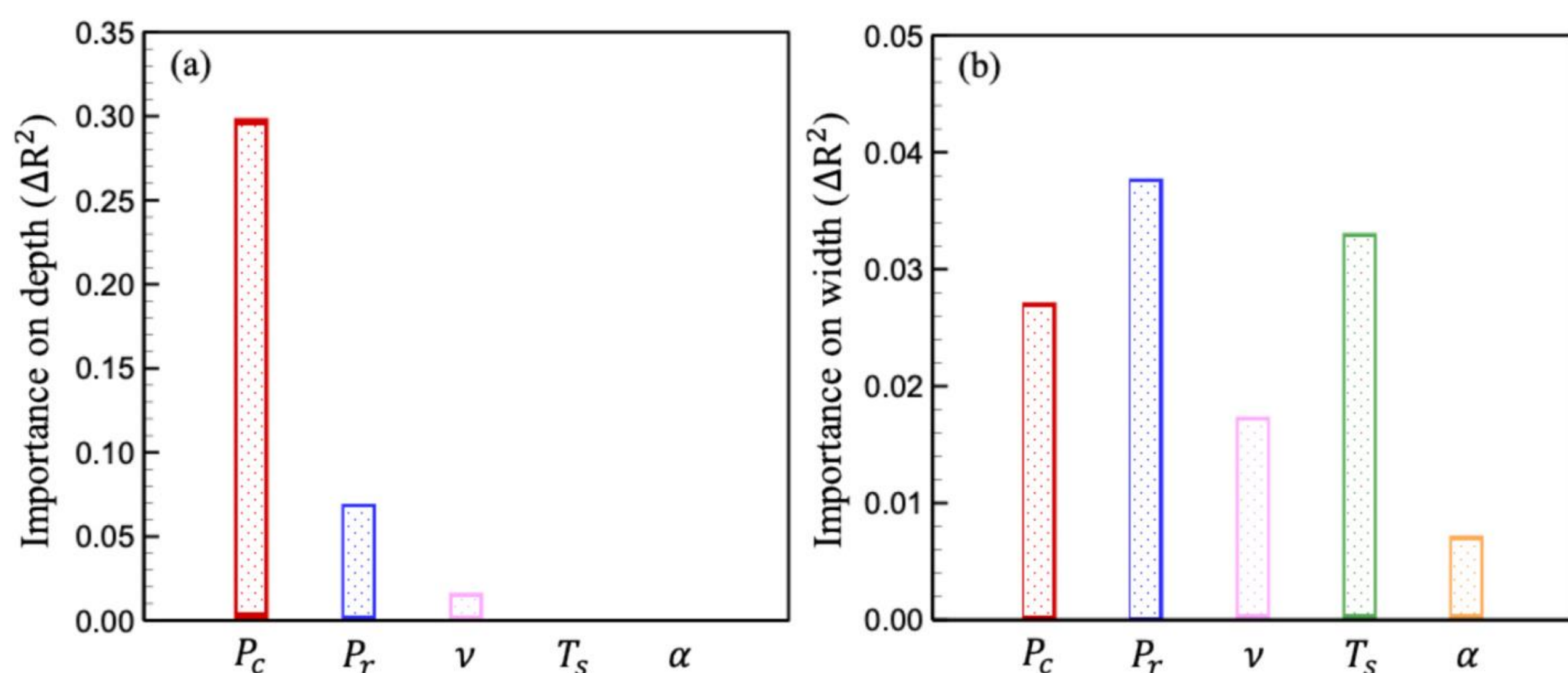


Figure 7. Hierarchical importance (ablation study) on melt pool (a) depth and (b) width.

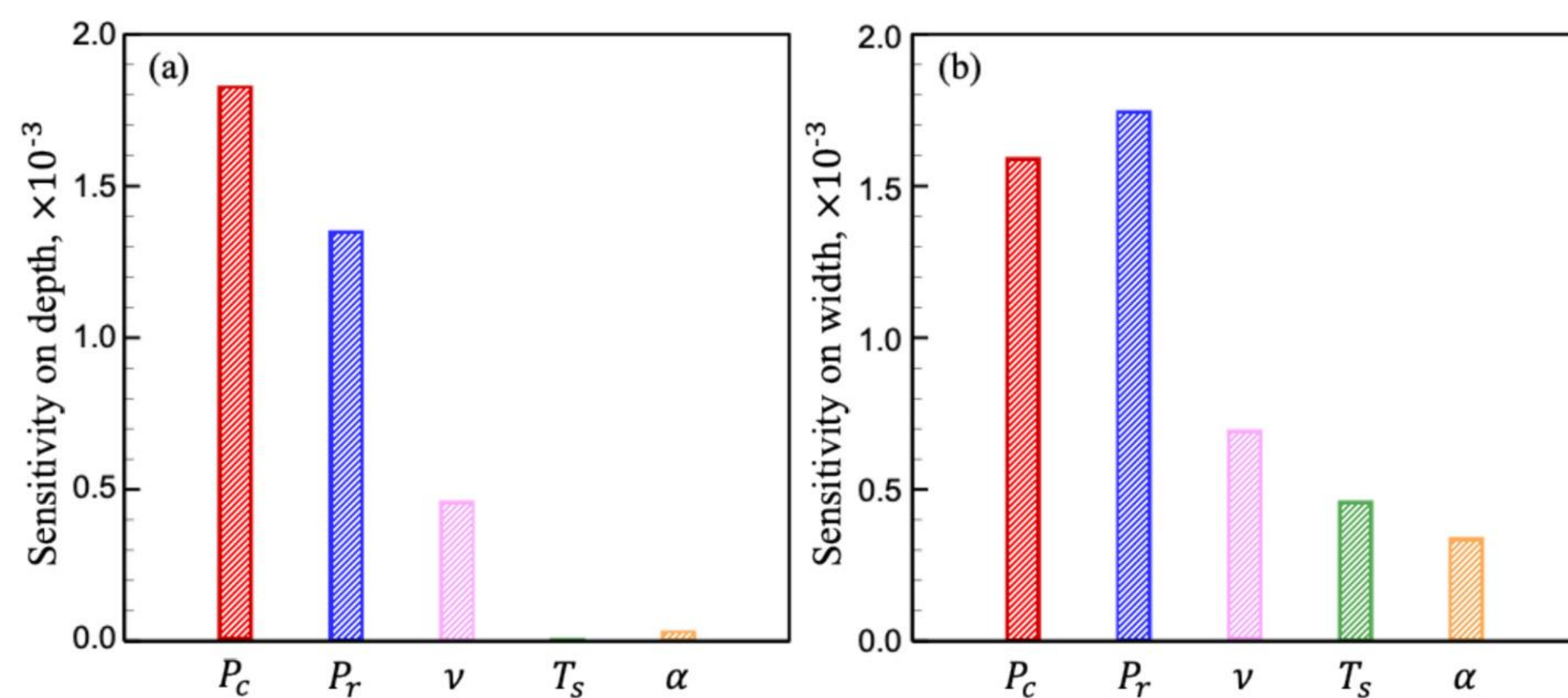


Figure 8. Sensitivity of depth and width to each variable ($\pm 20\%$ range); (a) depth, (b) width

5. Conclusions

- For DLAMB welding, increasing core power (with ring power reduced to hold total power constant) increases melt pool depth and decreases width, while increasing scanning speed decreases both.
- Two linear regression equations, derived from 72 DLAMB welds across the three alloys, predict melt pool depth and width ($R^2 = 0.98$).
- Core laser power is most important for depth and ring laser power for width; the resulting process maps give ready-to-use DLAMB process guidance.

Acknowledgement

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