Fracture behavior of Ti-Al laminated composite by bending test

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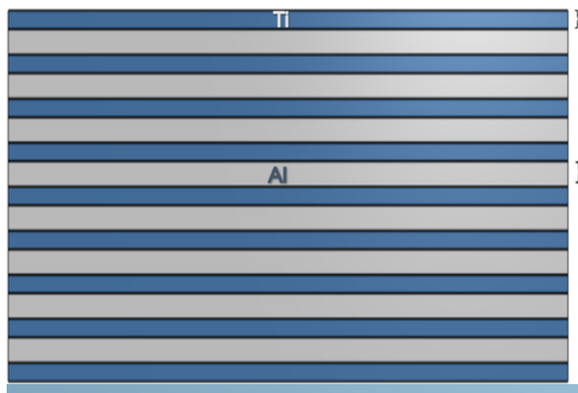
investigates the synergistic effects of electrical spark activation and temperature on interdiffusion behavior, phase evolution, and mechanical properties of Ti-Al laminated composites. The composites were synthesized via solid-state diffusion bonding in a vacuum at 600–750 °C for 24 hours. Phase identification using XRD and EDS confirmed the formation of a continuous titanium trialuminide ($TiAl_3$) intermetallic layer at the interface. Quantitative measurements showed that the layer thickness grew exponentially with temperature, adhering to the Arrhenius Equation. Three-point bending tests revealed that spark activation significantly reduced the percentage of interfacial delamination. At 650 °C, the spark-activated group achieved a minimum delamination of 32.59% and a peak Bending Stiffness of 54.24, a substantial increase from the baseline. In conclusion, the electrical spark process effectively enhances mechanical integrity and mitigates delamination-induced failure.

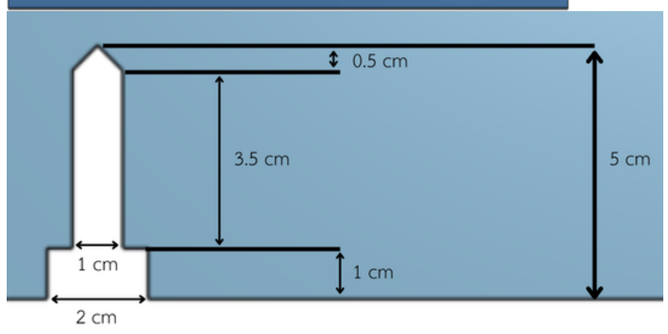
Pure Ti sheets and Al foils were stacked in a sandwich structure.

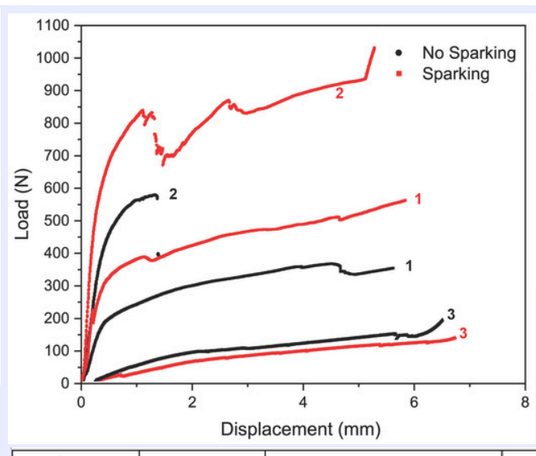
Samples were annealed in a vacuum furnace at 600–750 °C for 24 hours,

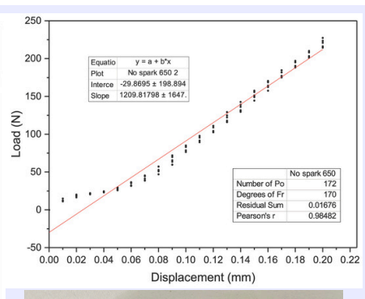
comparing Spark-activated and Non-sparked groups.

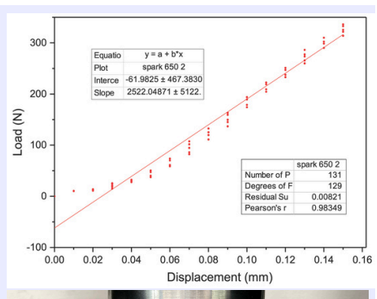
Mechanical properties were assessed via three-point bending tests, and microstructures were analyzed using XRD, SEM, and EDS.

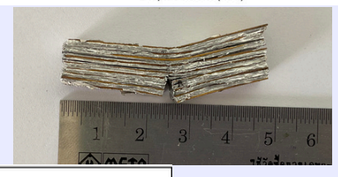






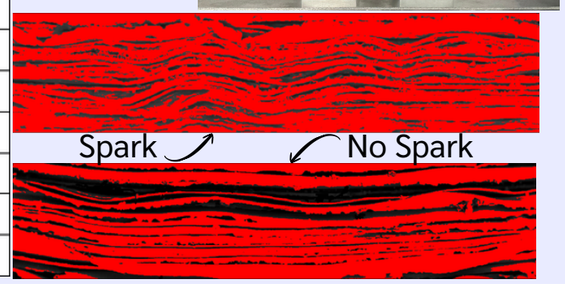


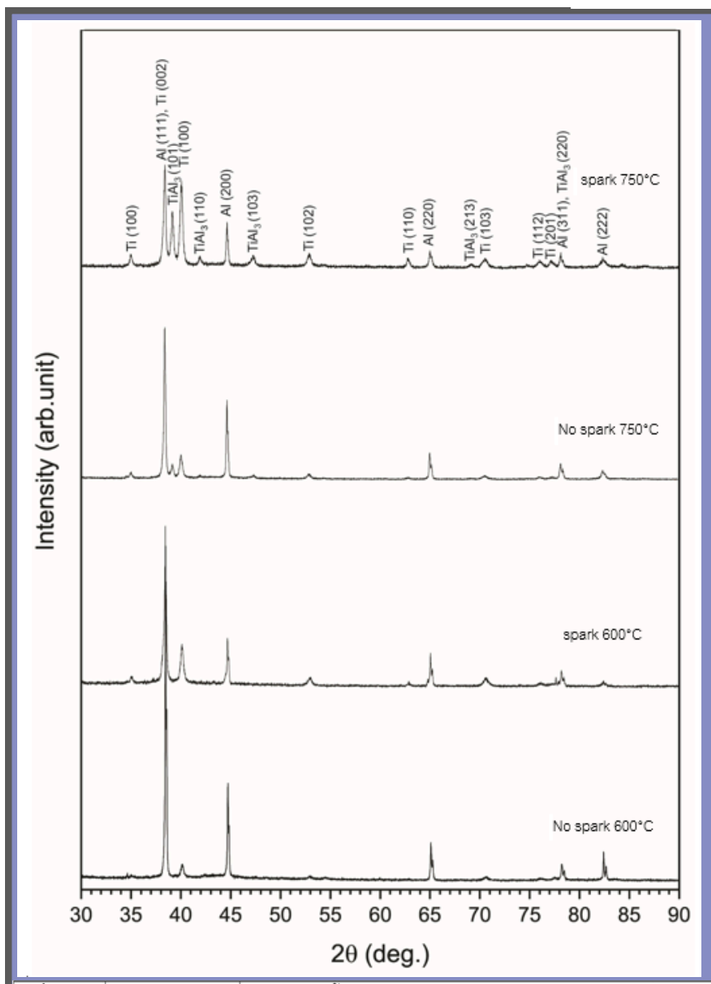


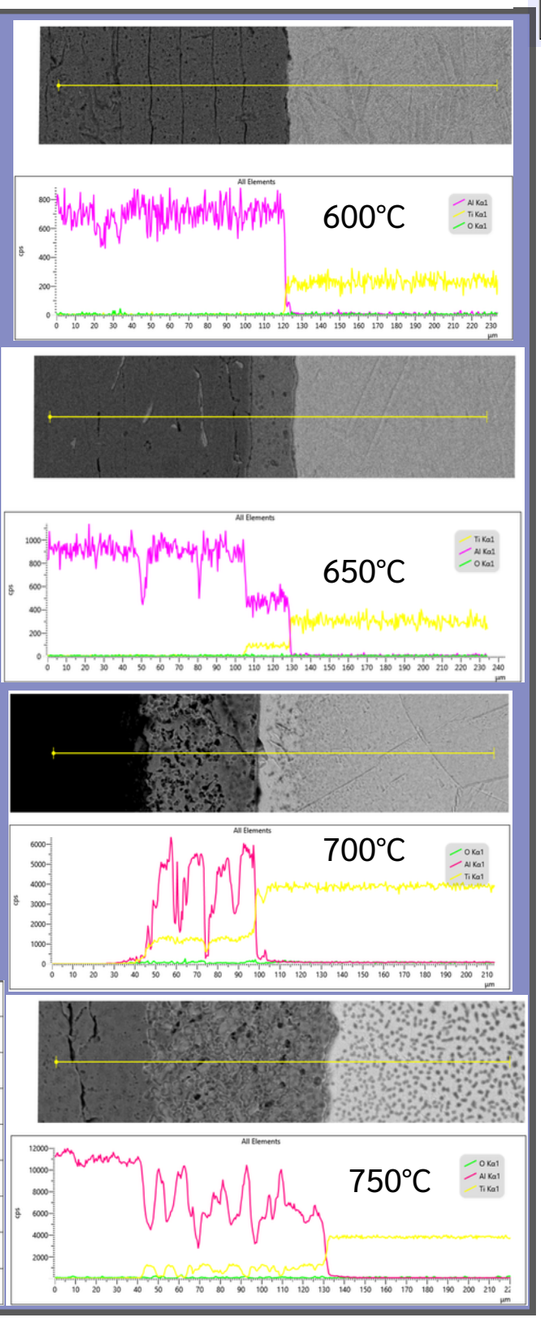




เงื่อนไข	อุณหภูมิ	Slop	% Delamination
No Spark	650-1	523.04	34.48
	650-2	1209.82	35.05
	650-3	63.34	37.58
Spark	650-1	1171.62	28.31
	650-2	2522.05	25.43
	650-3	37.23	27.75







เงื่อนไข	อุณหภูมิ	ความหนาชั้นสารประกอบอินเตอร์เมทัลลิก ($TiAl_3$)เฉลี่ย (μm)
Spark	600	ไม่เกิดสารประกอบ
	650	12 ±2
	700	54.67 ±5
	750	88.33 ±3
No Spark	600	ไม่เกิดสารประกอบ
	650	25 ±1
	700	81 ±10
	750	140 ±3

The XRD and EDS analysis confirms that the diffusion between Ti and Al layers leads to the formation of a single intermetallic phase, Titanium Trialuminide ($TiAl_3$). The growth behavior of this phase is strictly temperature-dependent, following the principles of chemical kinetics Reaction Threshold at 600°C: At this temperature, no intermetallic compound formation was observed under any condition. This is consistent with XRD patterns showing only the primary peaks of Ti and Al. This indicates that the thermal energy was lower than the Activation Energy (Q) in the Arrhenius equation, leaving atoms with insufficient energy to cross the interface. Critical Transition at 650°C: A distinct $TiAl_3$ layer begins to form, with an average thickness of 12 ±2 μm for the Spark condition and 25 ±1 μm for No Spark. This temperature is a critical point as it nears the melting point of Aluminum (660°C), significantly increasing atomic mobility. Exponential Growth at 750°C: The layer thickness increases dramatically to 88.33 ±3 μm (Spark) and 140 ±3 μm (No Spark). This leap confirms the Arrhenius relationship, where the diffusion coefficient (D) increases exponentially with temperature (T), leading to a greater diffusion distance (x) according to Fick's Law.

Mechanical Properties and the Influence of Spark Energy (Bending Test)

The fabrication temperature and the resulting $TiAl_3$ phase directly impact the mechanical performance, particularly when Spark energy is applied to stimulate the reaction Enhanced Bending Stiffness: Specimens under the Spark condition exhibited a significantly higher Slope in the Load-Displacement curves compared to the No Spark condition. Specifically, Trial 2 (650-2) showed the highest efficiency with a Slope of 2522.05, compared to 1209.82 for No Spark. This is because Spark energy promotes the formation of a high-quality, continuous $TiAl_3$ phase, which possesses much higher stiffness than the base metals. Interfacial Bonding Strength: Sparking consistently resulted in a lower percentage of delamination (% Delamination), ranging between 25.43% – 28.31%, whereas No Spark specimens showed higher delamination between 34.48% – 37.58%. This confirms that Sparking reduces the Energy Barrier, allowing for a more complete solid-state reaction and a bond that is stronger than natural diffusion. Energy Absorption Mechanism: In laminated structures, delamination serves as a mechanism for mechanical energy absorption to delay brittle fracture. Sparking helps control and strengthen this interfacial bond, making it work more effectively.

Summary of Findings

The experimental results clearly prove that temperature is the primary variable controlling the thickness and growth of the $TiAl_3$ layer according to Arrhenius and Fickian principles. Meanwhile, Sparking (Spark) is a highly effective secondary factor for improving mechanical properties by creating a high-stiffness intermetallic layer and reducing delamination. These elements are key to manufacturing Ti-Al laminated composites with superior strength and durability.

References

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