Entrapment of Al_2O_3 and SiC particles in 6061 Aluminum by Friction Stir Welding

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Abstract

Multi-layer armor comprised of stacked plates of ceramic and aluminum is common in light to heavy troop and equipment transports. While these armors effectively block projectiles they are expensive to produce and repair. The Friction stir welding (FSW) and the cold spray processes are evaluated for the use in bonding a ceramic powder top layer to a base plate of aluminum. The weld is then analyzed for microstructure and hardness. The use of ceramic powder with FSW should produce a bonded metal matrix layer on top of the aluminum plate with properties acceptable for use in armor at a reduced expense and increased ease of reparability.

1 Introduction

The friction stir process uses a rotating pin tool that is driven into the base material and the resulting heat and force causes the material below to plastically deform and weld together while staying beneath the melting point of the material. This limits defects caused by the heat of fusion welding and the distortion caused by the change from solid to liquid back to solid. The cold spray process uses a pressurized air gas stream to accelerate particles to a critical velocity at which then deform and bond to when they impact the base material.

Using cold spray Al_2O_3 and SiC powder is deposited onto the surface of ½ in. thick 6061 aluminum plate. Half of the deposits are then processed with the FSW machine and the samples produces from both stages are compared to an unprocessed plate for differences in hardness and microstructure.

2 Broader Impacts

Current armor configurations depend on layers of ceramic plates on top of aluminum. These plates are expensive to produce and impossible to repair. Ceramic particles in turn are inexpensive and readily available, commonly used at grit for media blasting. Successful use of these technologies with these ceramic powders could lead to more effective, cost efficient and easily reparable armors.

3 Procedures

Figure 1. The completed Cold Spray

The target base material is 6061 armor grade aluminum that was provided by Kaiser Aluminum for this project. The plate was placed in 10% NaOH for 15 min to remove any oxide layer that might interfere with the Cold Spray process. The SiC and Al_2O_3 powders used were granular 400 mesh. 325 mesh Al powder was used as a binder for the ceramics, and 325 mesh Cu was used as a tracer for microstructure analysis. These powders were mixed by weight to 50% ceramic, 45% Al, and 5% Cu, then cold sprayed onto the 6061 plate to a thickness of at least 0.06 in. See figure 1.

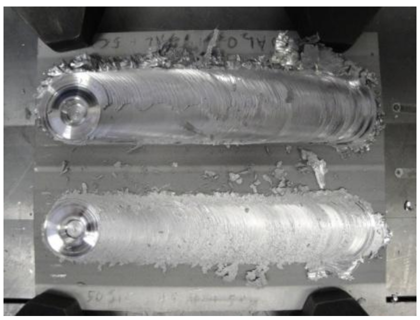

Figure 2. The completed FSW.

The samples then were welded on the MTS ISTIR 10 Gantry Intelligent Stir Welding machine at 300 RPM, with a smooth pin tool measuring 1.0in wide shoulder and a .125 pin length. See figure 2**Error! Reference source not found.**. After welding the samples were cut crossways to the weld, mounted in epoxy, and sanded down to 1200 grit, before getting polished down to a 1μm finish. Micrographs were taken at 200x by a Leco LX31 microscope. Finally a Vickers hardness test was conducted on the samples at 100g of load, and 15 seconds dwell.

4 Results

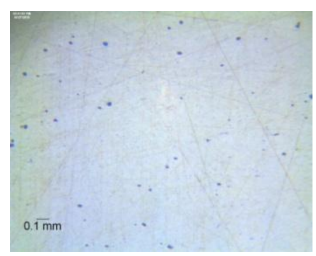

Figure 3. 6061 T6 plate.

The Cold Spray process was successful in produced a metal matrix composite coating with both sets of ceramic particles. See figures 4, 5. The FSW process broke up the larger ceramic particles and produced a relatively even distribution of smaller particles. See figures 6, 7. The pin tool used successfully made a surface weld with little or no dilution of the particles into the base plate material while providing an excellent bond with the surface layer. N final hardness and microstructure appeared between Al_2O_3 and SiC. However, the Al_2O_3 particles had a tendency to come loose while polishing. Microhardness of the Al matrix was softer than the 6061 plate, yet the point hardness on a particle was harder than the plate. See Table 1.

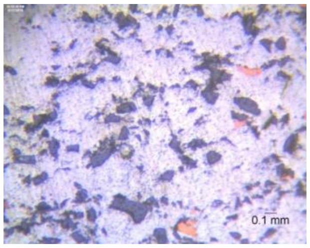

Figure 3. SiC deposit.

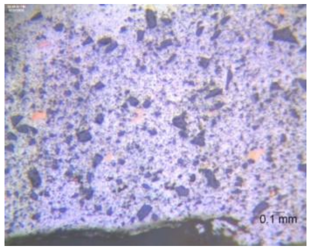

Figure 4. SiC welded.

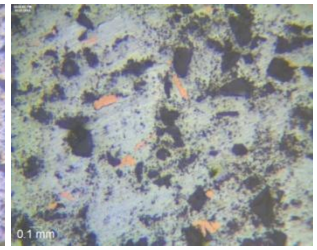

Figure 5. Al_2O_3 deposit.

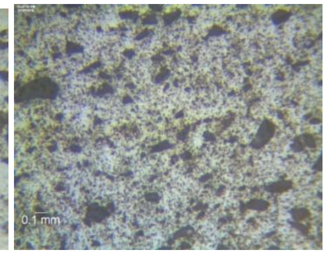

Figure 6. Al_2O_3 welded.

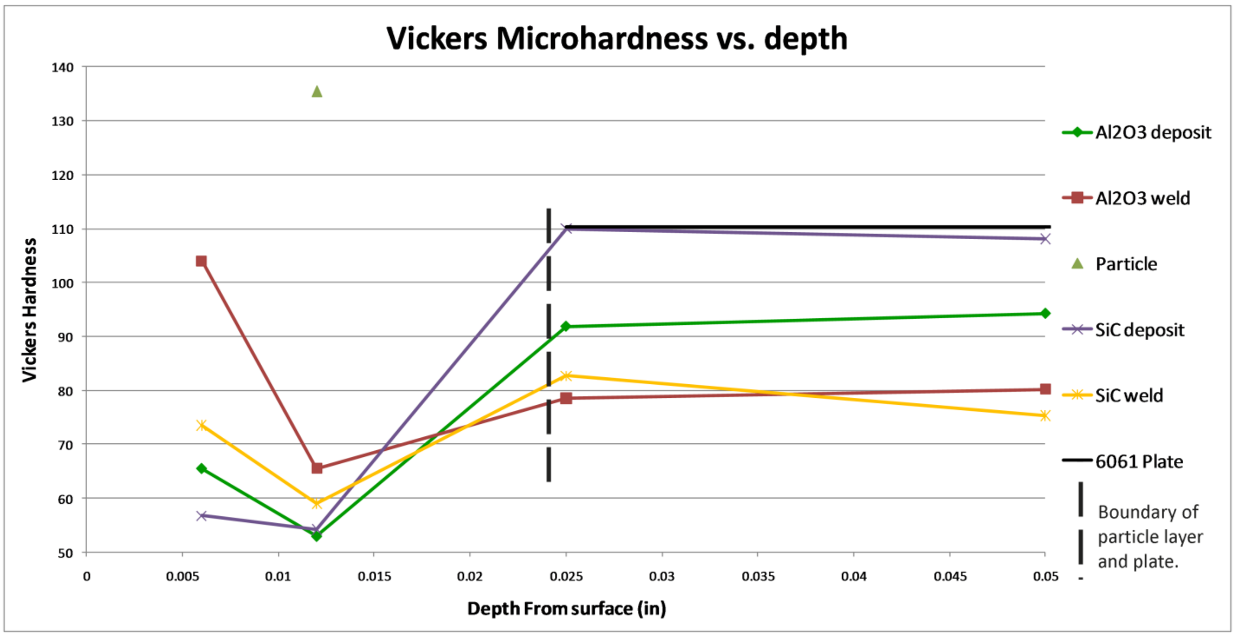

Table 1

5 Discussion

It was found that cold spray powder mixes with less than 45% by weight Al have greatly reduced deposition efficiency, with very little increase in the ratio of ceramic to metal in the deposit. This is suspected to be because the available cold spray machine is unable to obtain particle velocities where the ceramics will plastically deform and bond to the surface without a softer metal interlayer. The produced metal matrix composite proved to be readily stir welded. However, too deep of a shoulder plunge with the pin tool can prevent the metal matrix from reforming all the way across the weld. See top weld figure 2. Due to the small thickness of the deposit non-microhardness tests, such as the Rockwell, could not be performed. As such Vickers microhardness was used instead. However, it is not recommended for finding the overall hardness of a metal matrix composite due to the non-homogenous nature of the material at that scale.

6 Conclusions

It was found that the cold spray and FSW processes are capable of quickly producing thick, uniform metal matrix composites of Al with Al_2O_3 or SiC particles. The properties of the Al_2O_3 and SiC deposits are similar enough to share machine parameters. This is important due to the cost difference in the powders, with SiC being significantly less expensive. This allows future research and parameterization to be conducted with less expensive materials. The Vickers microhardness test showed that even in a matrix of material softer then the target hardness, the embedded particles would locally raise the hardness of the deposit to an acceptable level.

7 Future Work

The first step for further research would be to test thicker deposits for averaged hardness of the metal matrix, to see if the particles can raise the hardness on a macro scale. Changing the Al powder to a different alloy would help in producing the higher harnesses desired. Investigate if differently sized particles would help or hinder material properties. Adjustments to existing cold spray machinery to allow for more verity in the ceramic to metal ratio in the deposits. And finally to take the promising samples and conduct ballistic penetration tests to evaluative their performance as armor.

8 References

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