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Bimetallic Laser Deposition for Remanufacturing Applications

SUMMARY: As a continuation of its R&D of advanced manufacturing processes for the Department of Defense[1], Focus Hope Industries, Inc. (FHI) investigated the use of the additive manufacturing process laser metal deposition (LMD) for the application of remanufacturing high-value metal mechanical components of military systems. The material combination of Hastelloy C276 Ni-based alloy (deposit) and 4140 steel (substrate) was selected because of its potential application to remanufacturing or repair of many military system components. The remanufacturing process would entail removal of worn or damaged metal using typical machining processes, replacing the metal using the LMD process, and final machining to return the part to print requirements. Material test specimens of the deposit, substrate, and bimetallic materials were fabricated and subjected to mechanical testing as a step in the effort to have the LMD process certified for remanufacturing and repair of military system components. Mechanical test results show that the bimetallic Hastelloy/4140 steel material exhibits superior tensile, shear, and bending strength versus each of the constituent materials. Metallurgical analysis also supports these results by confirming a metallurgical bond by the presence of intermetallic compounds at the material interface region.

BACKGROUND – LASER METAL DEPOSITION: The LMD process combines the energy of an industrial laser and an automated stream of metallic alloy powder to apply a CNC-controlled molten bead of material onto a freestanding substrate or part. See Figure 1. The additive powder can be selected to provide equivalent or superior properties compared to the substrate material. As the laser beam advances along a pre-defined tool path in a layer-by-layer fashion, metal powder is deposited and eventually forms a pre-defined solid shape which is metallurgically bonded to the substrate. Due to the high cooling rates associated with laser-processing, the microstructure of the deposited metal is usually finer than the substrate's and the resulting material exhibits improved mechanical properties.

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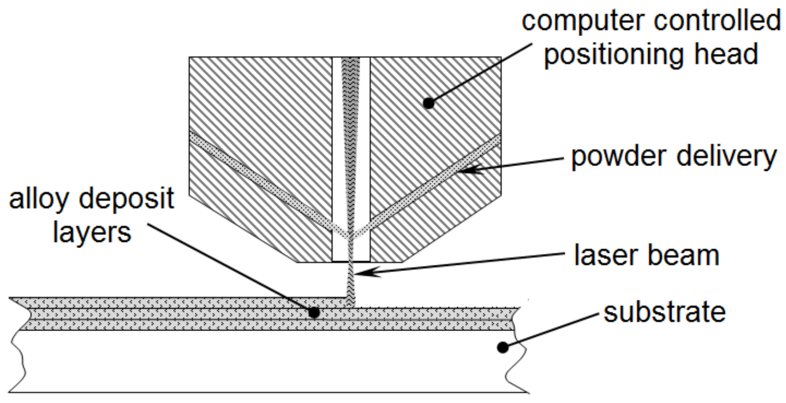
[1] U.S. Army Tank Automotive Research and Development Center Contract #W56HZV-C-072 and U.S. Navy Office of Naval Research Contract #N00014-07-C-0282



Laser Metal Deposition of a Dissimilar Alloy

FIGURE 1

TEST SPECIMEN PREPARATION: A set of LMD process parameters, including laser power, spot size, powder feed rate, and travel speed, was developed for each material and coupon design using an L9 orthogonal array experimental design. Using the optimized process parameters, two sets of material coupons were fabricated: 100% Hastelloy deposition and 50% Hastelloy (deposit) / 50% 4140 steel (substrate). See Figure 2 for test specimen configuration. By using substrate coupon designs that would simplify subsequent specimen extraction machining, we were able to prepare ASTM tensile and fatigue test specimens which contained both deposit and substrate materials with the crucial metallic interface region located within the neck of the test specimen. Bend test specimens were also fabricated to include two equal layers of deposit and substrate material. Equivalent test specimens of 100% 4140 steel substrate material were also fabricated.

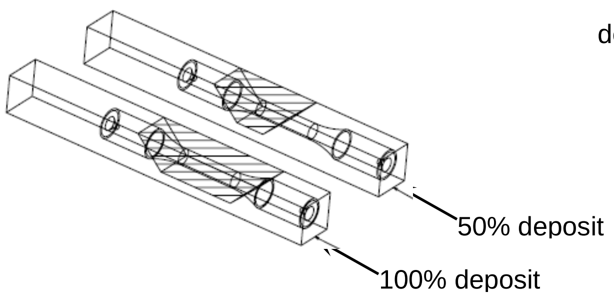


Figure2a – Fatigue Test Specimen

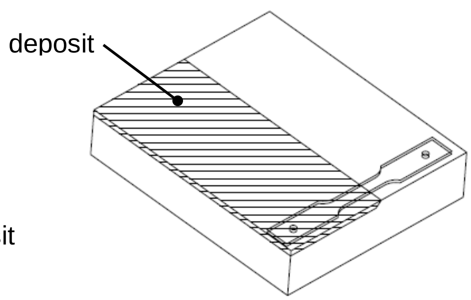


Figure2b – Tension Test Specimen

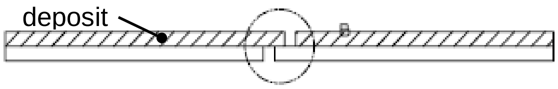


Figure2c – Shear Test Specimen

Figure2d – Bend Test Specimen

TEST RESULTS: As expected the Hastelloy deposit material displayed superior strength characteristics over 4140 steel with 53% higher yield stress, 29% higher shear stress and 13% higher flexural load. However the main purpose of these tests was to determine the strength characteristics of the bimetallic interface that would be created during an LMD remanufacturing process using the selected materials. The test results indicate that Hastelloy deposit/steel substrate material is significantly stronger than either of the two constituent materials with the bimetallic yield strength and shear stress being 74% and 52% stronger than the 4140 steel substrate respectively.

	100% Hastelloy	100% 4140 Steel	50% Hastelloy 50% 4140 Steel
Tensile Tests (ASTM E8)			
Yield (MPa)	661	431	749
Ultimate Tensile (MPa)	908	724	996
% Elongation	16	22	19
Lap Shear Tests (ASTM D3846)			
Max. Shear Stress (MPa)	434	337	512
3-Point Bend Tests (ASTM E290)			
Extension at Break (mm)	13.0	13.5	11.2
Max Flex Load (kN)	9.12	8.09	9.84
Angle (º)	87	91	77
Fatigue Tests (ASTM E466)			
Cycles before failure	10625	10597 *	9913

** 4340 steel deposited onto 4140 steel*