ABSTRACT

Additive Manufacturing (AM) is a process where components are created by continually adding material one layer at a time. Several benefits of "additive" manufacturing versus traditional "subtractive" machining processes include a reduction of material waste, ease of producing complex parts by reducing the amount of production steps, and the reduction of manufacturing lead-time. The Wire Arc Additive Manufacturing (WAAM) process, which uses Metal Inert Gas (MIG) welding, is demonstrated to analyze its potential application for maritime utilization. This study shows how the flexural strength yield of welded plates changes with different metal additive reinforcement. A standard 3-point bending test was conducted to determine the difference in flexural yield strength and to observe material behavior. Finally, it is discussed that AM processes, such as WAAM, are still being developed but their potential in the maritime industry, especially for the benefit of bringing supplies to our warfighters overseas, is clear.

INTRODUCTION

Wire Arc Additive Manufacturing (WAAM) is a Directed Energy Deposition (DED) processed defined in ISO/ASTM52900 as the "process in which focused energy is used to fuse materials by melting as they are being deposited". WAAM is the term used for all arc welding wire-based additive manufacturing processes. WAAM and its use in the maritime industry can have practical applications onboard vessels as printing replacement parts for mission critical engineering systems, as well as in shipyards for designing, prototyping, as well as fabricating actual end use parts such as propellers. This report analyzes the use of WAAM to reinforce metal plates using an industrial robot, MIG welder, and student designed and 3D printed parts. A homemade robotic welding 3D printer was designed and used to place additive layers on 1018 steel plates. Six metal plates had one weld bead and another six metal plates had two weld beads placed on them (one on top of the other) by the robotic welding 3D printer. In addition, six metal plates with no weld beads were used as a control for analysis. The 3-point bending flexural test was performed with an Instron machine to analyze the flexural properties of each of the weld plates. Finally, hardness testing was conducted and stress-strain curves were created to determine the flexural yield strength of each of the metal plates.

The cross section of the weld plates were modeled as rectangles with the weld beads being modeled as half-ellipses on the surface. Using the parallel axis theorem, the centroids of each shape was calculated and combined to get the total centroidal height of the cross section for use in the bending stress equation for development of stress-strain curves.

EXPERIMENTAL DESIGN AND THEORY

In the experiment, the WAAM 3D printer was used to put additive weld beads on metal plates. The different types of metal plates are one weld bead, two weld beads (one on top of the other), and a control plate with no weld beads. There are six metal plates for each of the three types of metal plates. The flexural strength and ductile behavior of the metal plates with various weld beads can be determined from the analysis of data from a standard 3-point bending test. The procedure used for the test was followed in accordance with ASTM D790 standard for performance of flexural tests.

EXPERIMENTAL RESULTS

The flexural yield strength for each of the metal plates is shown below. The average flexural yield strength for the metal plate with no welds, one weld, and two welds is 1000 MPa, 500 MPa and 823 MPa respectively. The flexural strength of the metal plates decreased as the welds were added to the plate. This may be due to the welding material and the temperature of the weld.

HARDNESS ROCKWELL B

The temperature of the weld can affect the hardness and the flexural strength of the metal. A heat treatment can be performed after welding, called Post Weld Heat Treatment (PWHT) to maintain or improve material strength and material properties. The drastic temperature change of the weld onto the weld plate can be seen in the discoloration of the weld plates after welding. The figure in the center column shows the weld plate discoloration on the underside of the weld plate. The decreased hardness on the welds can be explained by the additional temperature changes with the one weld and the two welds.

EXPERIMENTAL CONCLUSIONS

In this experiment, the effects of the flexural properties of 1018 steel were measured and analyzed after the steel was welded. The steel changed in its material properties including hardness and flexural yield strength. These material properties changed because of the high temperatures of the welding process and uncontrolled cooling. No post-weld heat treatments were performed in an attempt to maintain the material properties of the metal plates. The temperature of welding can change by changing the voltage of the welder. With less voltage, the temperature of welding will decrease, and this could mean the material properties of the metal could be maintained. When using metal additive manufacturing to weld reinforcement or create tool/objects, the material properties need to be understood in order to predict the quality and life of the material. For practical applications of WAAM in the maritime industry, it is important to note the material properties of metal after welding additive metal layers.

MARITIME APPLICATION CONCLUSIONS

Through extensive literature research and experimental work, it is shown that Additive Manufacturing, and WAAM in particular, has a clear future in the maritime industry. There are a great many types of AM processes that can be used for many applications within the industry. Prototyping for design work could be done with various types of printers but, in most cases, actual parts are made by Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS) processes. However, WAAM and WAAM in particular, is the closest to final production of actual parts by WAAM, as with any type of technology, the key is to develop and use each individual machine and consumable materials that are at your disposal. WAAM has a particularly good fit in the maritime industry because it is a relatively inexpensive technology for printing metals and can print in relatively large part dimensions compared to desktop sized models currently on the market.

REFERENCES

1. A. Garbhalo, Kolbe, Kihin KP ‘21, and the USMMA Marine Engineering Department for their time and expertise.

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Design of End Effector and WAAM System

A universal end effector was designed to fit most standard MIG welding guns and attach to an existing industrial robot arm. Over two design iterations, a final design was chosen that uses pipe clamps as securing bands and a pneumatic actuator which is controlled by the robot’s control system to press the MIG gun trigger. Fused deposition modeling (FDM) WAAM 3D printing was chosen as the method of manufacturing the end effector because of its ease of use and availability. A pneumatic actuator was chosen to allow the MIG gun trigger to be actuated without disassembling and re-wiring.

EXPERIMENTAL RESULTS

After the stress and strain for each metal plate was calculated, the data was plotted to make a stress-strain curve for each of the metal plates. The figure below shows one example of the stress-strain graph for weld plate #1. After the stress and strain results were calculated for each metal plate, the 0.2% offset method was used to help extrapolate the flexural yield strength for each of the metal plates. The blue portion of the graph is the elastic region of the graph. The orange portion of the graph is the plastic deformation of the metal plate. After the linear portion of the graph was determined and the 0.2% offset line drawn, the flexural yield strength was extrapolated using the intersection of the 0.2% offset line and the stress-strain curve.

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