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Spray Forming Technology for Military Applications*

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Over the past five years, the Annapolis Detachment, Carderock Division, Naval Surface Warfare Center (formerly David Taylor Research Center) has established a state-of-the-art spray forming facility for the study and exploitation of this near net shape manufacturing process. Spray forming is a single step gas atomization/deposition process which yields ferrous and nonferrous, near final shape, near fully dense preforms that has proven to be a viable and cost effective alternative to conventional metalworking technology for the production of material preforms with properties surpassing those of their cast and wrought counterparts. Current programs at Carderock Divison Naval Surface Warfare Center are aimed at optimization of the process, certification of the spray formed products and industrialization of the technology.

1. Introduction

HIGH-DEPOSITION-RATE spray forming is a new technology developed in Europe that significantly reduces the cost and improves the performance of a spectrum of engineering alloys. In the spray forming process, molten metal is rapidly atomized to form a fine spray of particles that are deposited onto a collector at rates of up to 182 kg/min (400 lb/min). The microstructure of the as-deposited preform is fine grained and uniform with minimum microporosity. Spray forming has proved to be a viable and cost-effective alternative to conventional metalworking technology for the production of material preforms, with properties surpassing those of their cast and wrought counterparts.

In recent work at the Naval Surface Warfare Center (NSWC), a program was initiated to identify and develop viable near-net-shape manufacturing methods to reduce the high cost of Alloy 625 piping (58Ni-22Cr-8Mo-5Fe-4Nb) while still maintaining or improving the properties of the final product. Previous work by a U.S. Navy piping supplier indicated that existing powder metallurgy (P/M) methods were capable of producing Alloy 625 piping at costs comparable to those of current fabrication techniques. A subsequent evaluation at NSWC demonstrated that P/M technology combined with standard hot-working processes can produce fully dense components with uniform, fine-grain microstructures. A suggestion from this work was that alternative near-net-shape manufacturing methods should be examined to determine the cost advantages and quality of the resulting products. Alloy 625 appeared to be a particularly attractive alloy for such a study because of its high processing costs. The processing costs are driven by the tendency of the alloy to segregate upon solidification, its high rate of strain hardening during metalworking, and its elevated-temperature strength.

Key Words: spray forming, superalloys, intelligent processing, military applications, near net shape manufacturing

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2. Research and Development Efforts

The NSWC program indicated that near-net-shape manufacturing, specifically Osprey spray forming, is a viable alternative for producing quality Alloy 625 tubular preforms. The Osprey preforms exhibited a fine, equiaxed microstructure and mechanical properties approaching the current specification for the extruded product. The spray-formed material seemed well suited to the roll extrusion process that is used to reduce tubulars to thin-wall piping for Navy applications.

Mechanical properties for extruded Alloy 625 piping reduced by conventional roll extrusion methods are presented in Table 1. The properties for piping manufactured from spray-formed preforms, P/M preforms, and conventional ingots are presented for comparison. All meet the ASTM specification for minimum tensile requirements. There is some variation in the tensile properties of the conventional and near-net-shape processed Alloy 625 piping. It is hypothesized that these small differences in properties are due primarily to differences in the

Table 1 Tensile results for near-net-shape processed Alloy 625 pipe

Piping material	Yield strength, MPa	Yield strength, ksi	Ultimate strength, MPa	Ultimate strength, ksi	Elongation, %
Conventional ingots	496	72	993	144	40
Fully dense P/M preforms	510	74	965	140	47
Spray-formed and roll-extruded preforms	483	70	1007	146	39
ASTM B 444-84 specification	414	60	827	120	30

final cold reduction, final annealing temperature, and chemistry of the various piping materials.

3. Alloy 625 Certification

Because of the success of the NSWC research and development efforts, spray formed Alloy 625 has been selected as a candidate for evaluation under the Foreign Comparative Test Program sponsored by the Office of the Secretary of Defense. This program will determine whether the Osprey process is certifiable as a viable low-cost alternative to conventional manufacturing of Alloy 625 piping for Naval submarine applications. The approach of this task is to produce seamless Alloy 625 piping via the Osprey spray forming process in specified nominal pipe size diameters ranging from 100 to 355 mm (4 to 14 in.) and to test all products for specification compliance. Testing includes nondestructive evaluation; dimensional, metallurgical, chemical, and mechanical inspections required in the product specification; low- and high-cycle fatigue testing; burst testing; and corrosion, fabrication, and welding studies of prototype piping configurations. Qualification will also include the specific processing methods used to work the preforms and/or reduce them to final form.

4. Intelligent Control

A program to implement real-time sensing of preform temperature, rate of growth, and quality (as indicated by surface properties) has also been undertaken at NSWC. The objective of the program is to develop sensor and control technology to monitor the critical process conditions and to modify parameters during the process to produce asymmetric components with repeatable microstructural quality. This task has been divided into two phases, the first of which entails development of sensors and controls to monitor and correct simulated process conditions. In the second phase, the selected sensors and controls are combined with actuators for integration with the NSWC equipment. Sensor data are used by a fuzzy-logic-based intelligent controller to make adjustments to primary process parameters, such as atomization gas pressure, droplet flight distance, and melt flow rate. These adjustments are made in small increments, and sensor feedback determines whether appropriate responses are obtained in the process. The goal is to maintain a quasi-static process state in which appropriate deposition layer thickness and temperature result in a fully dense preform with a fine, equiaxed grain structure.

The movements of the spray collector have been expanded beyond the current one-axis linear motion and one-axis rotational movement. The manipulator uses hydraulic actuators and has five axes of motion, including x (withdrawal), z (spray height), wrist roll, wrist pitch, and tool roll, with an optional y axis that can be added as required. Thus, it will become possible to produce asymmetric components, such as hemispheres, tapered tubes, and elbows.

In addition, a detailed, empirical process database has been developed that includes the monitoring of process conditions such as alloy type, microstructural quality, and preform soundness. A long-term goal of the program is to establish the relationship between preform microstructure and quality with processing practices in order to optimize and control the spray-forming method.

5. Industrialization and Technology Transfer

Results from the intelligent processing program will be combined with other NSWC developments in the optimization of the spray-forming process and integrated into a 4.5-ton pilot plant facility. The objective of this manufacturing technology program is to industrialize the spray-forming manufacturing process in the United States to reduce the cost of military components and to enhance the global competitiveness of U.S. industry. Navy applications such as torpedo tubes, shaft seals and sleeves, and bearings will be addressed. In addition, other service applications that have been identified will be evaluated and the cost-effectiveness determined.

Technical information and a plant for commercial manufacturing are being acquired through a contract that includes a performance specification for the plant and conditions for transferring the technical know-how to U.S. manufacturers. A competitive selection process is underway to choose the industrial site for installation and commissioning of the spray-forming plant. The domestic contractor selected will develop spray forming capabilities to produce specific components, including applications such as piping, gun barrels, and aircraft engine covers. Cost data will be developed for each application in production.

Selected References

- A.G. Leatham, R.G. Brooks, J.S. Coombs, and A.J.W. Ogilvy, The Past, Present and Future Developments of the Osprey Process, *Proc. 1st Int. Conf. on Spray Forming*, Osprey Metals, Ltd., UK, 1990
- A.L. Moran and W.A. Palko, Spray Forming Alloy 625 Marine Piping, *JOM*, Vol 40 (No. 12), 1988, p 12-15
- A.L. Moran and D. White, Developing Intelligent Control for the Spray Forming Process, *JOM*, Vol 42 (No. 7), 1990, p 21-24