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**CREATION OF LARGE CASTINGS
BY THE INVESTMENT PROCESS**

Final Report

March 1973

Bendix Corporation
Kansas City, Missouri

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THE CREATION OF LARGE CASTINGS BY THE INVESTMENT PROCESS

March 1973

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THE CREATION OF LARGE CASTINGS BY THE INVESTMENT PROCESS

Prepared by W. E. Cromwell

For many years the aluminum investment casting process has been used only for small to medium sized parts--approximately the size of a 3-inch (76 mm) cube to a 12-inch (305 mm) cube. Recent industry advancements in materials, equipment, and processing capacities permit investment casting of much larger parts. The investment casting process has been successfully applied to two of the largest known thin-wall aluminum parts conceived to date: the Case Section Controller and the Case Section Base. The A356-T6 aluminum alloy parts are 9 inches (229 mm) in inside diameter, 0.125 inch (3.2 mm) in wall thickness, and 19 inches (483 mm) and 26 inches (660 mm) in length, respectively. The castings replace a forged, machined, and welded plate assembly, and minimize the finished product fabrication time and cost. As the size barrier to investment casting begins to disappear, many potential applications may now be considered which previously were viewed as unrealistic.

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SUMMARY

The original designs of the Controller and the Base specified sections made of two 6061-T6 aluminum cylindrical forgings with machined 6061-T6 sheet and bar features welded into position; these assemblies required finish machining to meet design tolerances. During the initial development stages, it became apparent this design concept would result in high end-product cost because of the large amount of machining and assembly time.

After reviewing the design requirements, the Bendix and Sandia engineers agreed that investment casting potential warranted investigation. These questions required careful consideration.

- Could aluminum alloy investment castings offer the functional strengths required?
- Could agreement be reached on a design concept which minimized the amount of finish machining?
- Could such large investment castings be produced economically without compromising the final assembly's functional requirements?
- Could the investment casting industry successfully fabricate investment castings larger than those ever known to have been attempted?

To find the answers to these questions, five factors were considered: casting size, the casting source, the casting's functional design, the economics of production, and the ability of the casting to satisfy program function requirements. The Bendix Casting Engineer discussed these questions with Design Product, and Process Engineers, and the casting suppliers. It was concluded that with a proper development program, there was a strong possibility of success.

After reviewing the preliminary Bendix casting design with several suppliers of investment castings, and obtaining Sandia Laboratories' approval, Bendix placed a development order with Hemet Casting Company, Hemet, California, for three sets of castings. For Hemet to fabricate castings this large, they had to develop special handling equipment, increase capacities of several pieces of capital equipment, and formulate new processing techniques designed to yield extremely large castings that were both dimensionally accurate and metallurgically sound.

The first castings received were subjected to a thorough dimensional and metallurgical inspection, and finish-machined to the final product design. The finished Case Section Controller and Case Section Base were reinspected to confirm dimensional stability. Once confirmed, the castings were shipped to Sandia Laboratories for static load and tensile testing. The results confirmed that the castings satisfied all strength requirements, exceeding expectations for shock and static load.

Because of the success of the team development approach, and the successful testing program, the castings have been approved for production, with an estimated savings of over \$100 per unit set.

DISCUSSION

SCOPE AND PURPOSE

To explore the possibility of replacing forged, machined, and welded plate Controller and Base Assemblies with investment castings¹, these primary study areas were established:

- The possibility of producing extremely large precision aluminum castings using the investment process;
- Economic comparison of investment castings with normal raw stock fabrication methods; and
- The establishment of the investment casting's structural stability under static load conditions.

It was thought that successfully producing large aluminum investment castings could yield significant product cost savings.

PRIOR WORK

Bendix has been heavily involved in the use of investment castings since the middle 1960's. There has been a steady improvement in the quality of castings produced by the industry, and a continuous desire by producers and users to advance the state of the art. Although AEC product had benefited from this improvement by an expanded use of investment castings, aluminum investment castings of this size and structural integrity had not, to Bendix's knowledge, been successfully produced. The size limitations of the capital equipment available, and the lack of capacity in foundry process support facilities, were thought to be the primary causes inhibiting development of a large casting capability. It appeared these could be overcome with a coordinated team effort.

ACTIVITY

In an effort to reduce fabrication time and final unit cost, Bendix product engineers decided to try to replace the forged and welded sheet metal units, the Case Section Controller and Case Section Base (Figures 1 and 2), with a

¹ For those unfamiliar with investment casting process details, see Appendix A.

**Figure 1. Original Forged and Welded Sheet Metal Assemblies
Before Being Clamped Together**

**Figure 2. Original Forged and Welded Sheet Metal Assemblies
Clamped Together**

functional casting, using the "shell" process (Appendix A). Several factors were considered before launching a concentrated effort at casting development.

- Casting Size--Could investment castings this large be produced?
- Casting Sources--Would investment casting producers accept the challenge presented in fabricating castings of this size and integrity?
- Functional Designs--Could Bendix, Sandia, and the casting industry mutually agree on casting designs that would satisfy all needs?
- Economical Fabrication--Would it be economically feasible to produce extremely large castings by this investment process?
- Casting Function--Would the castings satisfy the program functional requirements of strength, maximum dimensional stability, and appearance?

Aluminum casting foundries were contacted and asked what problems might be encountered. In general, it was felt the castings would be successfully produced with close coordination between Bendix, Sandia, and the foundry, and with a significant increase in the foundry's equipment capacities and processing capabilities.

The initial casting designs were conceived with these three objectives in mind:

- Product functional strength and geometric configuration requirements had to be satisfied;
- Feature complexities had to be minimized to simplify casting tooling, processes, and finish-machine tooling; and
- The finished casting would have to be economically attractive when compared to a fabricated assembly produced from raw stock.

Bendix designed two investment castings (Figures 3 and 4) 19 and 26 inches (483 and 660 mm) long, with a 9 inch (229 mm) inside diameter and a 0.125 inch (3.2 mm) wall thickness, based on design and functional requirements of the original raw stock designs. These initial casting designs were reviewed in detail with several potential investment casting producers to obtain their viewpoints on castability and cost. When Bendix and the producers agreed that the design could be produced, the designs and development proposal were forwarded to the Sandia Laboratories for review. Sandia approved the design, and placed an order with Bendix for three sets of developmental castings. Bendix selected the Hemet Casting Company of Hemet, California, to make them.

Figure 3. Investment Cast Base and Controller Case Sections Before Being Clamped Together

Figure 4. Investment Cast Base and Controller Case Sections Clamped Together

The casting material selected for use was A356-T6 aluminum alloy with specially-increased physical property limits to help assure functional strength requirements (Tables 1 and 2).

Table 1. A Comparison of Material Requirements and Test Results for A356-T6 Aluminum Investment Castings

Mechanical Properties	Minimum Required by Specification 7431393	Test Results*
Ultimate Tensile Strength in psi (MPa)	38,000 (262 MPa)	44,100 (304 MPa)
Yield Strength in psi (MPa) With 0.2 Percent Offset	28,000 (193 MPa)	31,700 (218 MPa)
Elongation (Percent in 4D)	5.0	10.4
*Average obtained from testing of seven separately cast test bars processed with the development castings		

Hemet had to expand equipment and process capacities throughout the product flow system to successfully produce such large castings. They designed and built the wax pattern tooling, and developed or altered some of their facilities to process the castings. They improved their methods of handling the heavy wax pattern molds, not only for safety reasons, but to prevent damage to the wax patterns during disassembly and removal of the patterns from the mold. They developed a workable plan for a gating system that would effectively feed sufficient molten metal to fill the large amount of thin walls and reinforcing structural members; the gating system would also provide the support necessary to prevent the undesirable sagging of the wax pattern during application of the shell material--the ceramic slurry and refractory grain (Steps 3 and 4 of Figure A-1).

Table 2. Chemical Composition of
A356-T6 Aluminum *

Element	Percent by Weight	
	Minimum	Maximum
Copper	---	0.20
Silicon	6.5	7.5
Iron	---	0.20
Manganese	---	0.10
Zinc	---	0.10
Magnesium	0.20	0.40
Titanium	---	0.20
Others, Each	---	0.05
Others, Total	---	0.15
*Radiography as defined by Bendix Specification 9921013 is Grade R.		

The first set of castings was successfully poured and finish-processed at Hemet with Bendix engineers in attendance. Afterward, a dimensional inspection revealed some minor dimensional defects, and each casting when X-rayed had one minor flaw in an isolated, nonstructural area. Since these conditions were correctable and a negligible factor with respect to the planned test program, these castings were finished and shipped to Bendix for final machining.

Once received by Bendix, the castings were dimensionally inspected to confirm the results reported by Hemet. Upon completion of final machining (which was minimized to assure dimensional stability and lower finished-product cost), the set of castings was alodined and shipped to Sandia Laboratories for structural testing.

Sandia's test program consisted of subjecting the Controller and Base Assembly (both castings fastened together with a modified Marman clamp) to two static load tests. These tests simulated dropping the final assembly from a 48-inch (1.2 m) height, and also simulated the shock of "humped" railroad cars. The acceptable load limit for the drop test was set at 20,000 pounds (88.96 kN) distributed over three points--5,000 pounds (22.24 kN) to be applied to each end, and 10,000 pounds (44.48 kN) to be applied near the center connecting point. A dial indicator was set to measure deflection (Figure 5).

Figure 5. Lateral Test of Base and Controller Casting Assembly. A 48-Inch Drop Was Simulated With an Inertial Load of 100 g's. The Load Was Increased in 10-Percent Increments

The maximum indicated deflection was 0.048 inch (1.219 mm) with no permanent distortion measurable at load removal. Since the assembly had successfully passed this test, it was destructively tested by removing the load from each end and applying a constantly-increasing load near the center connection point next to the clamp. The unit did not yield until a force of 21,500 pounds (95.63 kN) had been applied, at which point the clamp began to spread apart. After removing the clamp, the castings were examined and found free of structural damage.

The acceptable load limit for the railroad hump test was set at 6,250 pounds (27.80 kN) with a 50-percent safety factor added, bringing the total test load to 9,375 pounds (41.70 kN). This test was performed on the base casting only. The casting was mounted so that the load, applied by a jack, would tend to break the clamp flange (Figure 6). Although 9,375 pounds was the acceptable limit, the casting was successfully tested up to the jack's 17,000-pound (75.62 kN) limit. To test the maximum strength of the casting, another more powerful jack was attached to the setup. The casting was tested to 24,000 pounds (106.75 kN), or 2.5 times the acceptable limit, before breaking in the clamp ring area.

The casting was chosen for production use (Figure 7), based on the results of the structural test program, and the lower part cost afforded by the investment castings. Although the final design is in evolution, it appears that the casting will be used in production and that it will provide the anticipated cost savings.

ACCOMPLISHMENTS

The largest known thin-wall aluminum investment castings have been successfully produced and have passed all testing, including static loads and shock. As a result of the coordinated team effort, the casting design is considered to be a functionally acceptable replacement for the forged, machined, and welded plate assembly. This replacement will yield an estimated cost savings in excess of \$100 per unit set. A level of confidence has been established in the potential usage of large investment castings for possible future applications.

FUTURE WORK

Several areas will require continued effort to realize the potential benefits offered in the successful production and application of large investment castings:

Figure 6. Axial Test of Base Casting. A Load of 47 g's for 20 Microseconds Was Simulated. The Inertial Load Caused by Response was 50 g's

Figure 7. Production Investment Casting. This Illustration Shows a Developmental Casting Which Incorporates a Design Change (Bar Added) Which Will be Added as a Cast Feature.

- Improvements in the supplier's processing and capital equipment;
- Increased activity in the area of effective casting development programs; and
- Refinements and design concepts directed at improving casting producibility, machinability, and reducing casting cost.

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Appendix A

INVESTMENT CASTING PROCESSES

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Figure A-1. Investment Shell Casting Techniques

Figure A-2. Investment Flask Casting Techniques