38.0 ON DEMAND CASTING OF NET-SHAPE TITANIUM COMPONENTS FOR IMPROVED WEAPON SYSTEM RELIABILITY

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This project initiated in Fall 2018 and is supported by the Defense Logistics Agency. The research in this project will be performed by undergraduate students.

38.1 Project Overview and Industrial Relevance

Titanium is a desirable material for the production of lightweight components because of its high specific strength, good corrosion resistance, and high temperature properties. The supply chain for near net-shape titanium components can be expanded by the development of high-volume casting methods such as die casting. However, due to the high melting temperature of titanium, conventional ferrous die materials will have extremely short lives. In addition, titanium is a difficult material to melt and process.

This project is part of a three-university effort to address the feasibility of titanium die casting. The specific tasks for each university are as follows:

- Improve the production of titanium components by leveraging the latest on-demand melting technology (University of Alabama, Birmingham)
- Expand the die casting process to high melting temperature casting alloys (CSM)
- Explore alloy modifications to improve castability (CSM)
- Evaluate/develop degassing technology for molten titanium alloys (Purdue University)

The project at CSM will focus on (1) the identification of candidate high temperature resistant die materials and coatings for titanium casting, (2) provide a coated tool for the demonstration of on-demand casting of titanium, and (3) provide an improved titanium alloy composition for die castability and high-performance properties.

38.2 Previous Work

There have been previous attempts to die cast titanium and this project will leverage those efforts.

38.3 Recent Progress

Work is continuing to identify a suitable mold material that will last for the production of at least 1,000 titanium castings. The focus has been on reviewing the mold materials examined in previous efforts to die cast high melting temperature metals. Four main efforts have been identified as listed below:

- GE (1960s)
  - Ferrous die casting
- Mitsubishi (1990s)
  - Centrifugal casting of Ti-alloys
- Howmet (1990s)
  - Ti-die casting
- United Technologies (2010s)
  - Die casting of single crystal superalloys

The work performed by GE in the 1960s is especially interesting. In 1969 GE published a 465-page report documenting their attempt to die cast ferrous alloys such as 304 stainless steel, and the report included an evaluation of die life focusing on 23 different die materials, most fabricated from refractory metals such as molybdenum- or tungsten-alloys. The casting mold used for the GE study is shown in Figure 38.1, and the casting parameters used in the study are listed in Table 38.1, and are similar in nature as would be used when die casting titanium alloys. The results from their die life study are summarized in Table 38.2, which is extracted directly from the GE report. This shows that several die materials were able to produce more than 15,000 castings and appeared to be still in relatively good condition at that point.

GE decided that the two die materials listed below had performed well enough to be considered for use in a pilot plant casting operation. All were molybdenum alloys.

- Mo-3
- TZM

GE produced the hollow hemisphere component shown in Figure 38.2 in this pilot die casting operation. The hemisphere castings were produced from malleable iron. GE produced a total of 2,761 shots in the pilot operation and indicated that while the dies appeared to be still in good condition at the end of the trial, close observation indicated that a few minor cracks had started to form.

38.4 Plans for Next Reporting Period

Successful accumulative roll bonding of Al 1100 has provided opportunity for process and tooling development. Work to follow in the next reporting period includes the following:

- Develop proficiency in microstructural characterization techniques for aluminum alloys including anodizing for grain contrast, transmission electron microscopy and electron backscatter diffraction.
- Conduct high temperature tensile testing of ARBed Al 1100 with Gleeble to better understand effects of temperature and strain rate on mechanical properties.
- Explore ARB processing of other aluminum alloys including 5083, 5182 and 5754.
- Quantitatively measure bond strength in roll bonded aluminum alloys subjected to preheating before rolling and post-deformation heat treatments.

38.5 References

[38.1] D.J. McMillin, A High Temperature Alloy Die Casting Process, Air Force Materials Laboratory Technical Report AFML-TR-69-223 (1969).

38.6 Figures and Tables

Table 38.1: Casting parameters [38.1]

Parameter	Value
Alloy	304 stainless steel
Liquid metal temperature	1500-1600°C (2730-2910°F)
Plunger speed	12-17 ins/sec
Metal pressure	8,400 psi
Die temperature	400-650°F
Dwell time	2 seconds
Cycle time	Up to 4 shots/minute

Table 38.2: Data from GE report showing number of castings produced for different die materials [38.1]

Material	Number of Cycles Experienced	Condition	Mode of Deterioration
Cu-infiltrated W	2	Failed	Brittle failure (mechanical--not in cavity)
H-13	728	Failed	Plastic deformation (cavity)
Cu-infiltrated Mo (2% Be-Cu)*	2,745	Failed	Heat checking/erosion
Anviloy 1150	2,585	Failed	Heat checking/erosion
Cb-752	4,017	Failed	Gross cracking
GE-474*	7,017	Failed	Erosion/heat checking
P&S W-2% ThO_2+	3,470	Poor	Random brittle failure/erosion
Anviloy 1150	8,992	Failed	Heat checking/erosion
P&S W+	6,055	Fair/Poor	Random brittle failure/erosion
80-20*	8,992	Failed	Random brittle failure/heat checking
Wrought Mo	8,990	Failed	Brittle failure (delamination)
Cb-25% Zr+	8,285	Fair	Heat checking
Hi-density, P&S Mo (insert retainer plates)	8,992	Failed	Gross cracking/plastic deformation
Wrought Mo (insert retainer plates)+	6,055	Good/Fair	Gross cracking/brittle failure (delamination)
Silicided wrought Mo+	6,055	Very good	Plastic deformation (gap formation) brittle failure (delamination)
Wrought Mo+	15,047	Fair/Poor	Brittle failure (delamination)
Hi-density, P&S Mo+	8,285	Very good	Plastic deformation
Hi-density, P&S Mo	15,047	Fair/Poor	Plastic deformation (gaps and dents)/gross cracking
HOT SHOT 2920X*+	14,792	Fair	Heat checking
HOT SHOT 2920X*+ (solution annealed)	14,319	Good	Heat checking
Hi-density, P&S Mo+	15,047	Good	Plastic deformation (dents)
TZM+	15,047	Good	Brittle failure (delamination)
Mo-3*+	15,047	Good	Pitting/heat checking

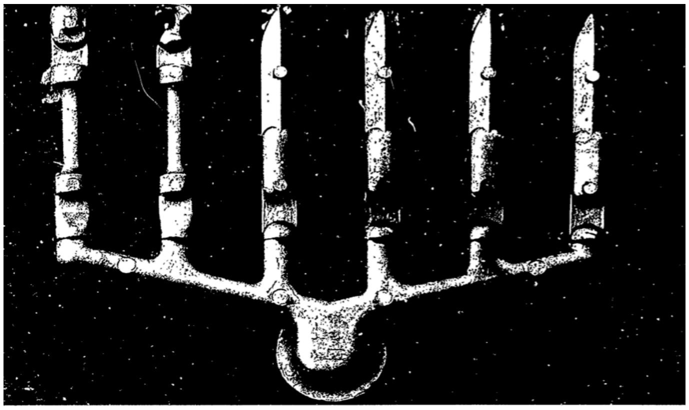

Figure 38.1: Multi-cavity die used by GE in the die life study [38.1].

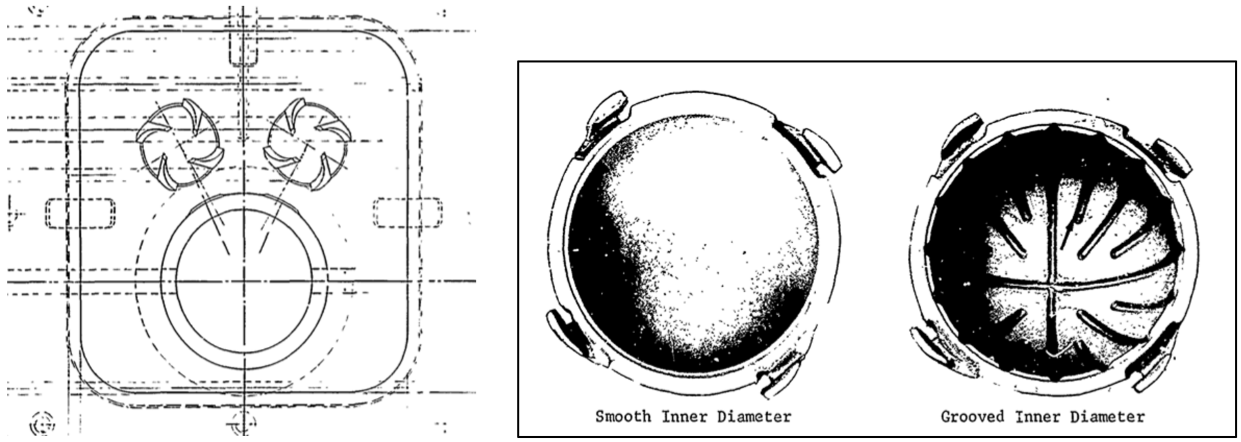

Figure 38.2: 2-cavity hemispheres die used in the GE pilot plant casting operation [38.1].