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The Potential of Squeeze Casting for the Production of Near Net Shape Uranium Parts

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ABSTRACT

This report was written to provide a detailed summary of a literature survey on the near net shape squeeze casting process. Squeeze casting was evaluated as a possible method for achieving the goals of the LANL program titled Near Net Shape Casting of Uranium for Reduced Environmnental, Safety, and Health Impact. In this report the squeeze casting process is reviewed and an assessment of its ability to achieve the near net shape and waste minimization goals of the LANL program is made. It is concluded that although squeeze casting is capable of producing near net shaped parts and reducing the amount of subsequent machining (thereby decreasing wastes), to use the process with uranium would require the design of a unique piece of equipment capable of performing the melting, pouring and squeezing operations in close proximity and in a vacuum.

I. INTRODUCTION

The purpose of this report is to describe the squeeze casting process and to determine whether or not this technique could be applied to the production of uranium or uranium alloy castings of near net shape. The advantages of producing uranium or uranium alloys with a near net shape technique are greater material yield, less hazardous material waste generated and a subsequent cost reduction. This report begins with a general description of the squeeze casting process, followed by discussions of the advantages of the process and the experimentally determined metallurgical and mechanical process parameters of importance. This report is concluded with a section on the potential of using squeeze casting for the production of near net shape uranium or uranium alloys.

The research findings on a simulation of plutonium squeeze casting are also summarized in this section since plutonium is a dense, low conductivity, very reactive metal as is uranium.

II. PROCESS DESCRIPTION

Squeeze casting is sometimes referred to as liquid metal forging or extrusion casting. The actual technique is basically a hybrid of the forging and permanent mold casting processes. Squeeze casting consists of pouring a specific amount of metal into the lower half of a mold, closing the mold, and then allowing the metal to solidify in the mold under pressure (8-15 ksi) between the plates of a hydraulic press.[1] The applied pressure displaces the metal to fill the mold or die cavity and aids in the elimination of interdendritic porosity by pressure feeding the molten metal. The mechanics of the process are usually carried out in the manner illustrated in Fig. 1 (Ref. 1). The charge metal is melted and transferred into the preheated die cavity. The tooling is then closed allowing the melt to solidify under pressure. Upon complete solidification, the casting is ejected, the dies are cleaned and the process is repeated as necessary with a fresh molten charge.

III. ADVANTAGES

Some of the advantages associated with squeeze casting are listed below:

A. Near Net Shape Capability and Part Complexity

Squeeze casting is often used to make near net shaped parts. An associated advantage of being able to achieve closer dimensional tolerances is a subsequent reduced machining cost. The process is easily automated to produce near-net to net shape high-quality components. Complex parts and thin sections which are difficult to form in conventional forging and casting processes can be formed via squeeze casting. In addition, a substantial reduction in pressure requirements in comparison to conventional forging can be obtained.

B. Efficient Use of Raw Material

Improved yields, sometimes as high as 100%, are achievable in several applications such as in engine pistons, disk brakes, automotive wheels, truck hubs, bushings, gears, missile components, differential pinion gears, and mortar shells.

C. Process Automation

Many steps in the squeeze casting process may be automated.

D. Mechanical Properties

This process generates the highest mechanical properties attainable in a cast products with the added benefit of excellent surface finish.

E. Unit Cost Reduction

With the incorporation of automation, high production rates are possible. This, in conjunction with reduced machining costs and the elimination of the labor associated with sand casting (molding, trimming risers and gates, cleaning), usually leads to a significant reduction in item unit cost.

IV. METALLURGICAL AND MECHANICAL PROCESS PARAMETERS

The process variables of importance in squeeze casting are the melt temperature, the melt volume, the cleanliness of the melt, the accuracy of the pour into the die, the duration time of the metal flow into the die, the die surface temperature, the punch temperature, the advance speed of the top punch, the time delay before pressure application, and the pressure level and duration. Each of these parameters is described below.

A. Melt Temperature

The selection of a melt temperature is important for several reasons. First, is die life. The melt temperature should be kept low to prolong die life. However, it should be kept high enough to give a good surface finish and internal quality.

B. Melt Volume

An accurate system of metering the melt volume into the die should be established. If the melt volume is too low, incomplete mold fill will occur. If the melt volume is too high, excess flash and jetting of the molten metal out of the dies can occur. Bobrov et al.[3] controlled the accuracy of the melt volume in their work by submerging a float of known volume into the molten metal crucible thus causing a melt overflow of the corresponding volume.

C. Cleanliness of the Melt

Care must be taken when pouring the melt into the die to prevent any dross or slag from entering the die. This is usually done by placing dams in the crucible or by using a filtration system during the pour. When dross does pour into the die along with the melt, it often plasters itself to the die walls and leads to major surface defects in the final casting.

D. Accuracy of the Pour

M. Virani et al.[4] have experimentally determined that if the melt pour was not exactly centered into the die cavity, nonuniform liquid fill occurred. This led to turbulence, splatter on the die walls and erosion of diffusion-inhibiting parting agents which lead to defective castings and welding of the casting to the die.

E. Duration of Metal Flow

Pour times are usually determined with experimental casting runs. Technically, shorter times are preferred because this leads to a lesser degree of die wall freezing, minimizes any reactions between the die walls and the melt, and provides less heat transfer to the melt. The latter is important to avoid the formation of too much of a solid crust or skull which offers too much resistance to the squeeze pressure and thus does not allow proper die fill during pressurization.

F. Die Surface and Punch Temperatures

It is necessary to preheat the squeeze casting die and punch to delay solidification before the onset of pressurization. However, the maximum temperature selected should consider tempering effects of the die material, whereas the minimum temperature selected should consider what temperature will provide reasonable die toughness and also minimize thermal gradients which lead to thermal stresses.[5]

G. Punch Advance Speed

In general, this speed needs to be as rapid as possible to minimize solidification of the static liquid in the die cavity.

H. Time Delay Before Pressure Application

According to Bidulya,[6] the squeeze casting pressure should be applied at the moment of zero fluidity. This is the time at which there is a continuous network of solid-phase skeletons formed in a two-phase alloy. The time of zero fluidity can be associated with a temperature of zero fluidity which is approximately the midpoint of the solidus-liquidus temperature range. At the zero fluidity temperature, the punch is able to work the material with the least amount of pressure required to obtain a sound, homogenous casting. There is often a time delay involved as the melt cools to the temperature of zero fluidity. It is critical that pressure not be applied too soon (at higher temperatures than the zero fluidity temperature) as this will lead to rupture of the solid crust with subsequent metal flow from the inner liquid over the ruptured crust leading to the formation of defects.

I. Pressure Level and Duration

These parameters are best determined experimentally and tailored to a specific part to be squeeze cast. Generally, the lowest pressure with which sound castings may be produced is specified. Often, there is also a duration time specified for the level of pressure. In most cases, some pressure duration is necessary to avoid producing cracked parts.

V. CONSIDERATIONS IN THE APPLICATION OF SQUEEZE CASTING TO URANIUM AND URANIUM ALLOYS

Although squeeze casting appears to be an attractive process for making near net shape uranium or uranium alloy parts, thereby reducing the production of hazardous wastes, some significant operational changes would need to be made to safely handle uranium or uranium alloy melts. Because molten uranium and its alloys will burn in air, vacuum melting is a must. This, however, complicates the mechanics of the squeeze casting process. Not only would the melting need to be conducted in vacuum, but also the squeeze casting process itself. This would necessitate the design of a unique piece of equipment, a combination of furnace, crucible and forging press capable of operating in a vacuum. The design of such a hybrid machine could be a significantly costly effort.

In 1986, Dorcic and Cheng[7] performed a simulation of a plutonium squeeze casting using lead, a metal which has a low conductivity similar to plutonium. The lower portion of a mortar body round was used to simulate a hemispherical shaped part. In this study, the die was instrumented with thermocouples to determine the nature of the thermal gradients during the squeeze casting process. Based on the results obtained, recommended process parameters for a squeeze cast plutonium hemishell shaped part were made. These were: 1) melt temperature = 1500 to 1600°F, 2) tooling temperature = 800 to 900 °F, 3) die closing time = 10 to 15 seconds, 4) pressure = 110 to 170 tons (10 to 15.7 ksi), 5) pressure duration = 30 to 60 seconds and 6) time before ejection = 60 seconds. However, no suggestions were made concerning plutonium's material compatibility with the die and punch or the need for protective coatings on the die and punch. No recommendations concerning how the process could be conducted entirely in a vacuum were made either.

However, if cost were no option and the process mechanics problems were solved (including die design and selection of a die and punch material compatible with uranium) other issues would then need to be addressed. These are the actual process parameters themselves: melt temperature, melt volume, the cleanliness of the melt, the accuracy of the pour into the die, the duration time of the metal flow into the die, the die surface temperature, the punch temperature, the advance speed of the top punch, the time delay before pressure application, and the pressure level and duration. These parameters were ususally determined by trial and error experimentation techniques in the past where one variable at a time was changed and its influence on the final casting was determined. However, today, squeeze casting could be investigated with computer modeling finite element codes combining heat transfer and fluid flow events to obtain a baseline set of processing parameters. These initial process conditions could then be verified with an experimental casting. The resulting casting could then be analyzed and the processing parameters optimized further with subsequent modeling and experimental efforts.

By combining modeling and experimentation together, much time, effort and money could be saved in comparison to the trial and error technique. However, before uranium squeeze casting could be selected as a reasonable means of achieving near net shapes and waste minimization, a cost-benefit analysis should be performed and compared to similar analyses of other near net shape fabrication methods to determine which process is capable of achieving a program's goals within reasonable costs.

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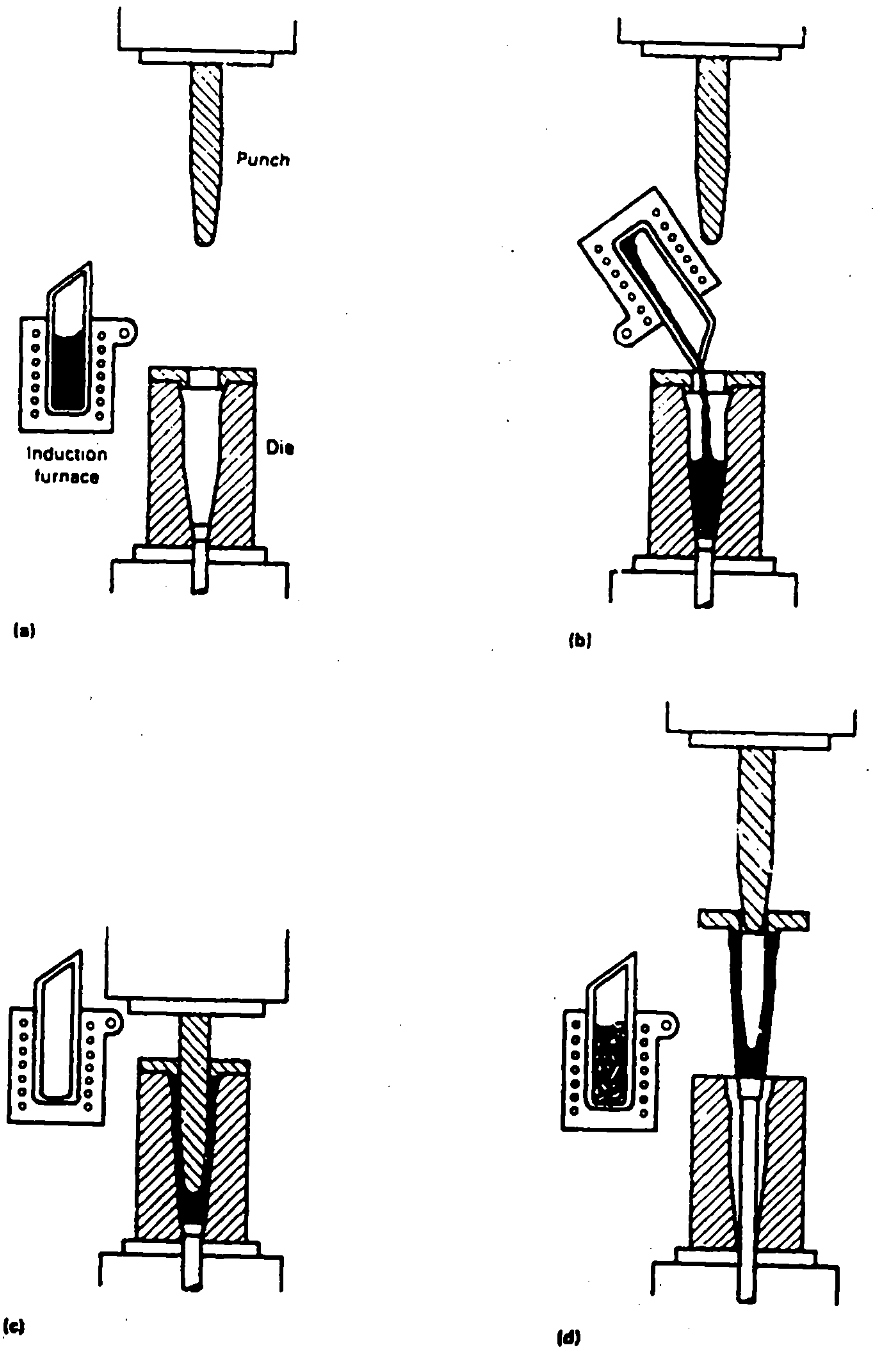

Fig. 1 Schematic illustrating squeeze casting process operations. (a) Melt charge, preheat, and lubricate tooling. (b) Transfer melt into die cavity. (c) Close tooling, solidify melt under pressure. (d) Eject casting, clean dies, charge melt stock (ref. 1).