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FOAMED METAL LOW DENSITY CORE MATERIAL FOR SANDWICH CONSTRUCTION

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WADC TECHNICAL REPORT 52-51
PART 2

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FOAMED METAL LOW DENSITY CORE MATERIAL FOR SANDWICH CONSTRUCTION

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Wright Air Development Center
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FOREWORD

This report was prepared by the Bjorksten Research Laboratories, Inc., under Contract No. AF 33(038)-21838 S1 (52-126). The contract was initiated under Research and Development Order No. 614-15, "Structural Sandwich Constructions", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. F. W. Kuhn acting as project engineer.

This report is the second in a series of reports on the same subject. The first report was published in June 1952 under the basic report number (WADC TR 52-51) only; it should be considered as Part 1 although it was not so marked.

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FOAMED METAL LOW DENSITY CORE MATERIAL
FOR SANDWICH CONSTRUCTION

INTRODUCTION

In previous work (described in WADC Technical Report 52-51) metallic low density foams were prepared from magnesium-aluminum alloys. The most effective procedure involved the use of a foaming agent which consisted of a mixture of either zirconium or titanium hydride and the magnesium-aluminum eutectic (54.4% magnesium and 45.6% aluminum). The melted foaming agent (hereinafter also referred to as the "eutectic-hydride foamer" or the "eutectic-hydride mixture") was incorporated into molten aluminum at a temperature slightly above the melting point of the aluminum. Upon solidification of this mixture, a metallic foam was produced with a density of about 15-20 pounds per cubic foot.

This report reviews the continued work on the improvement of the foaming process and equipment for the preparation of specified samples. Section I describes the development of a procedure for the foam preparation and Section II the development and construction of prototype equipment for preparing foam samples.

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SECTION I

FOAMING PROCESS

Basically, the procedure consists of melting the metal to be foamed, stirring in the foaming agent, releasing hydrogen from the hydride, and solidifying the foamed metal.

In practice, the process is not quite so simple. Aluminum in the molten state resists oxidation by the formation of a thin oxide film at its surface. Magnesium, however, oxidizes readily on exposure to air, and may ignite. An atmosphere of argon during processing is an effective means of preventing oxidation and protecting the surface of the molten mixture to be foamed.

The quality of the hydride used in the foaming agent influences its wettability by the molten metal and affects the dispersion of the foaming agent in the molten metal. For example, one batch of zirconium hydride gave considerable trouble in the mixing. Its wettability was reduced and large amounts were lost as dust because this particular batch was more flocculent and of a finer particle size than the previous material. Checking with the manufacturer disclosed that the purer form of the hydride tended to be flocculent and finer grained. In addition, the presence of 1 or 2% of impurities gave a more granular product that was easier to handle in the foaming process.

Still another factor is the necessity of a uniform mixture prior to foaming. Such a mixture of foaming agent and molten metal is not produced readily because the high surface tension, viscosity and specific gravity of the molten metal make stirring exceedingly difficult. Furthermore, the foaming agent must be dispersed rapidly into the molten metal to minimize its waste and to insure a uniform foam. Thus, thorough mixing is essential.

To improve the dispersion of the foaming agent in the base metal and to improve the consistency of the foam, mechanical stirring was instituted. This was accomplished by using as a stirrer, a disc of stainless steel, 2 inches in diameter, cut at the radius in 4 or 5 places with the blades bent so that they formed a multi-bladed fan. The stirring unit was mounted at the end of an 18 inch long, 3/8 inch diameter rod driven by the stirrer motor operating at 800-900 rpm.

By controlling the ratio of the eutectic-hydride foaming agent mixture to aluminum, the composition of the final alloy can be predetermined. For example, in 18.3 grams of the eutectic-hydride mixture containing 18% of the

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hydride, there are 3.3 grams of the hydride and 15.0 grams of the eutectic alloy containing 54.4% or 8.2 grams of magnesium. To produce a 95% Al-5% Mg alloy foam, 18.3 grams of eutectic-hydride are mixed with 150 grams of pure aluminum. Since the eutectic can hold well over 50% of its weight of hydride, the procedure is flexible enough to produce practically all of the commercial Al-Mg alloys.

The recommended procedure in use at present for producing metallic foams involves the following:

A. Preparation of eutectic-hydride foaming agent:

1. Melt the magnesium-aluminum eutectic in a crucible and maintain the temperature below 500°C.
2. Add zirconium or titanium hydride in small quantities and grind it thoroughly into the molten metal before adding additional hydride. Too rapid addition tends to make the final mixture too friable.
3. When the required amounts of hydride have been added, stir the mix to a smooth, pasty, slightly stiffer consistency.
4. Cool the mixture and break it up into 1/4" pieces. Grind in a mortar to produce particles which are retained on a 40 mesh screen after sifting through a 16 mesh screen.

B. Preparation of foamed metal:

1. Heat an empty crucible to 650-700°C.
2. Add the required amount of eutectic-hydride foaming agent.
3. Concurrently with steps 1 and 2, heat the metal to be foamed to slightly above its melting point.
4. When the foaming agent melts, pour the molten metal to be foamed into the crucible containing the foaming agent. As the temperature rises, foaming occurs.
5. Mix thoroughly until appreciable foaming subsides.
6. Remove the crucible containing the foamed mixture from the furnace and quench in cold water.
7. Remove the foamed metal from the pot.

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SECTION II

FOAMING EQUIPMENT

Essentially, the equipment consists of a device to prepare the foaming agent separately and another for mixing the foaming agent and molten metal to produce the metallic foam. The following discussion describes the development of these to their present state.

A. For Preparation of Foaming Agent

Initially, a very crude mixture of the eutectic-hydride mixture was made. Since mixing was performed manually, a considerable amount of oxide formed and the foaming agent was comparatively non-uniform and heterogeneous in composition. The importance of uniformity in the foaming agent and thorough dispersion in the molten metal to produce a uniform foam is obvious. The presence of excessive oxide in the eutectic-hydride mixture is also undesirable because it produces a discontinuity and consequent weakness in the foam structure. Since relatively large quantities of foaming agent are required, the development of a mixer to produce eutectic-hydride mixtures of good quality was necessary.

For this purpose a mixer was designed consisting of a metal box about 4" x 4" x 4" with two rollers at the bottom of the box working counter to each other. The rollers were one inch in diameter and the length of the inside of the box. They were knurled to aid in carrying the metal during the mixing process. In operation, a weighed portion of eutectic was melted in the mixer and the rollers started at about 150 rpm. The hydride as zirconium hydride was added slowly in small increments as the mixing progressed. Difficulty was encountered when the dry hydride worked into the bearings and froze, necessitating the disassembly of the mixer for cleaning. Greater clearances were cut on the bearings and the mixer reassembled. A second run was made with more success. However, this mixer was not considered suitable because the quality of eutectic-hydride made in this mixer was not superior to that made by hand mixing.

Another model was constructed to simulate closely the planetary action of hand mixing. It consisted essentially of a straight-sided flat bottomed crucible about six inches deep. A central shaft supported a planetary mixing rod that would bear on the sides of the crucible as the shaft was rotated. This model did not work well enough but indicated the feasibility of the design.

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A final model was made where the mixer would rotate on its own axis as well as describe a planetary path around the sides of the crucible. This model worked very well and was used to make all of the eutectic-hydride mixture subsequently used (Figures 1 and 2).

A relatively clean, oxide-free mixture can be prepared with relatively little difficulty in this device. Carbon dioxide gas is used as the ambient atmosphere. At the processing temperatures for preparing the foamer, carbon dioxide is satisfactory, since it does not decompose as it does at the higher temperatures used in the foaming process. The gas is preheated before being directed into the crucible and thus prevents freezing of the eutectic with subsequent binding of the mixer at the point where the gas impinges on the inside of the crucible.

With the availability of a mixer capable of controlling the temperature, surrounding atmosphere, and other factors, the quality of the eutectic-hydride mixture was significantly improved. By controlling the temperature closely and maintaining a non-oxidizing atmosphere in the crucible, mixtures containing a negligible amount of oxide and other foreign matter could be made. The consistency of the clean eutectic-hydride mixture was quite different from the material made by the hand mixing method. When made in the mixer, the foamer containing about 15% hydride was almost fluid as compared with the heavy paste from the hand method. Another improvement was the relative ease and speed of dispersion of the eutectic-hydride mixture in the aluminum when using the oxide free material.

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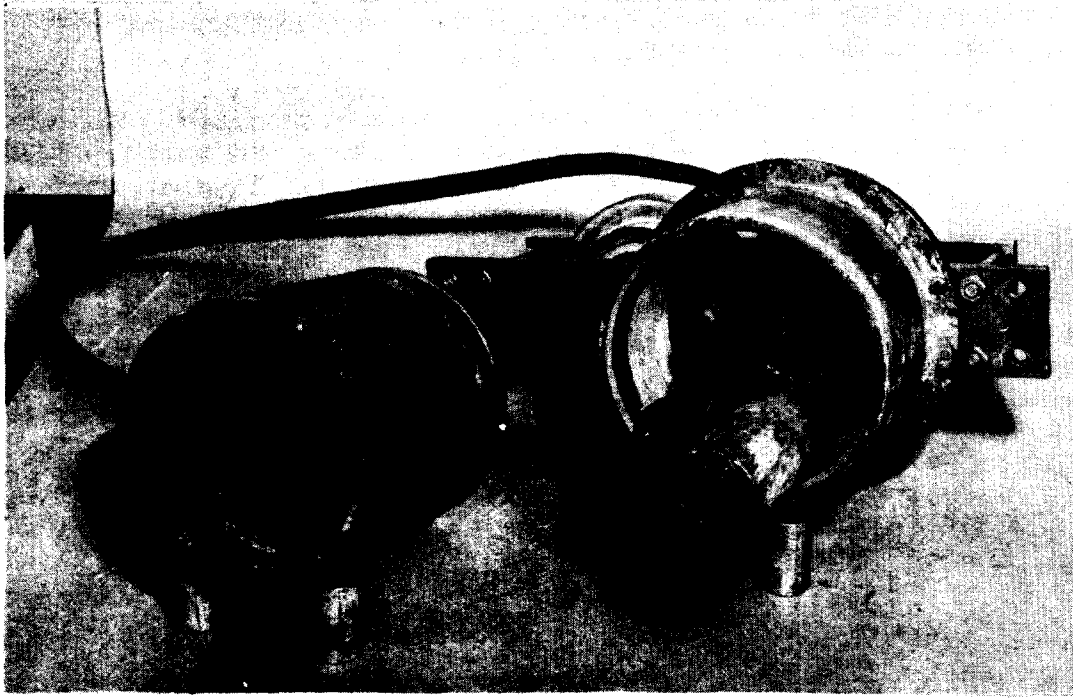
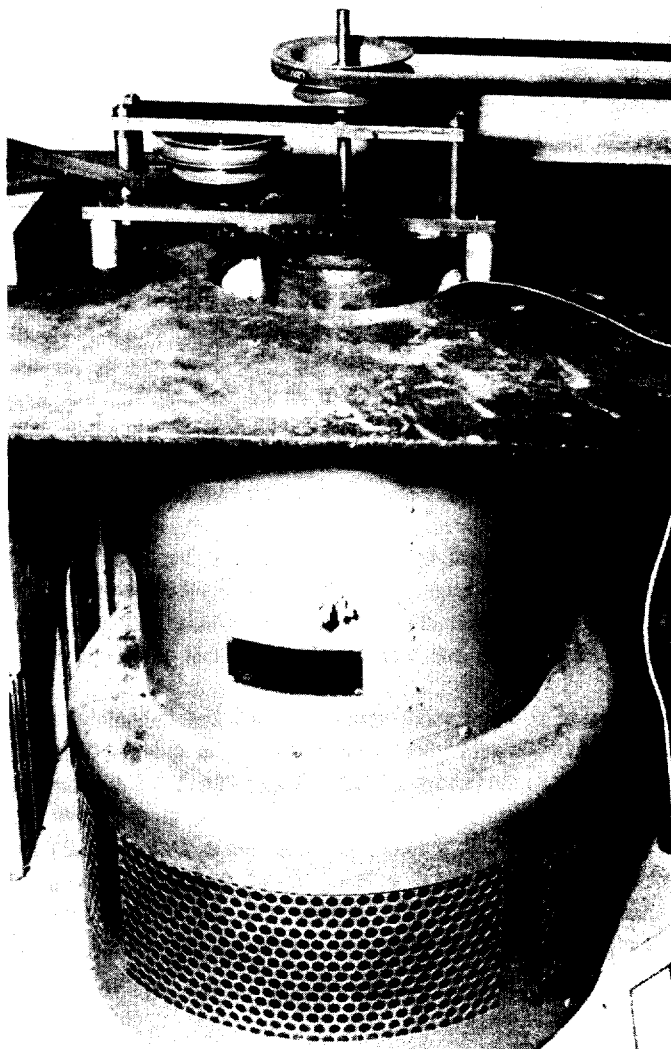


Figure 1. Disassembled Mechanical Mixer for the Preparation of Eutectic-Hydride Foaming Agent. At the left is the crucible in which batches of foamer are mixed. The assembly at the right houses and supports the mixing device.

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**Figure 2. Assembled Mechanical Mixer
Positioned in Furnace.**

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B. For Preparation of Foamed Metal

A mold and crucible were first used for producing foamed metal. These permitted inadequate control and did not produce large enough samples so that an extruder was designed and constructed. The following describes the development of each of these, emphasizing the difficulties encountered as the work progressed.

1. Mold and Crucible

To produce foamed metal samples large enough so that their mechanical properties could be evaluated, a mold was constructed into which the foam would flow from a crucible where the foaming mixture was prepared (Figure 3). The eutectic-hydride foamer was introduced into the molten aluminum or aluminum alloy to be foamed in the crucible by means of a tube and plunger. The tube was a six inch length of 1/8 inch pipe that had been reamed smooth and the plunger a rod of machined cold rolled steel.

This procedure proved unsatisfactory because the tube was constantly in contact with the crucible. At the temperature of the crucible, the eutectic-hydride mixture became overheated while in contact with the tube and decomposed before it could be mixed with the molten aluminum.

An injector was then built that could be heated separately and that would maintain the eutectic-hydride mixture at a controlled temperature prior to mixing with the molten aluminum. It consisted of a one inch pipe, ten inches long, with a plunger operated by means of a screw thread through a pipe cap at one end of the pipe. This screw was turned by hand with a crank. At the other end of the injector was a cap that tapered to a 1/4 inch orifice. The injector was loaded with eutectic-hydride mixture and heated to about 475 - 500°C. in a refractory tube wound with nichrome wire.

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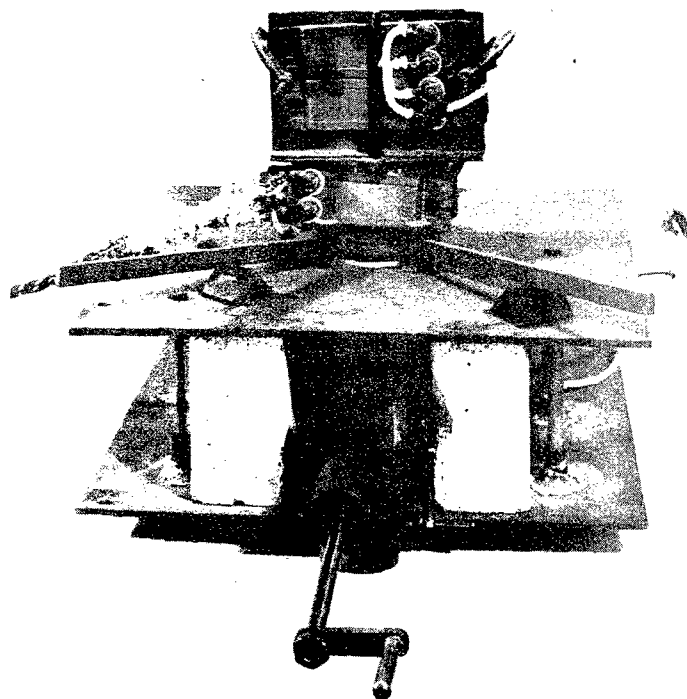


Figure 3. Mold and Crucible for Preparation of Foamed Metal.

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In operation, the tapered end of the injector was plugged into a hole in the side of the preheated crucible at about 700°C. As the crank was turned, forcing out the eutectic-hydride mixture, molten aluminum was poured into the crucible. At the same time, the stirrer was started. This method was not too satisfactory. The low temperature of the injector top as compared with the melting point of aluminum caused some aluminum to solidify in the orifice of the injector, plugging it and interrupting the flow of eutectic-hydride mixture into the crucible. No foamed material was produced by this method.

As a modification of the above process, compressed slugs of the eutectic-hydride foamer and varying mixtures of hydride and eutectic and aluminum powder were used. These slugs were introduced into molten aluminum by pushing them through a 1/8 inch pipe with a plunger in much the same way the eutectic-hydride foamer as powder was introduced in the first efforts to foam in the mold. These slugs were prepared by compressing the powdered materials, containing a small amount of mineral oil as a binder, in a compression mold at a pressure of 5000 pounds on a 4-inch ram. Slugs 1/4 inch in diameter and about 1/2 inch long were produced in this manner. Among the slug compositions tried were those containing the standard eutectic-hydride mixture with 15% hydride, as well as mixtures of 1:1 to 1:3 hydride and eutectic and aluminum powder.

Some foamed material was made by this procedure. However, the method lacked proper control and was inadequate for producing large samples.

2. Extruder

Previous work had indicated that only small amounts of aluminum could be foamed at one time. Consequently, to furnish samples of aluminum large enough for the desired tests, a continuous foaming process was considered. For continuous processing, an extruder-type mixer similar to a plastic extruder was investigated. Essentially, such a device would be a barrel containing a rotating mixer with a means for forcing aluminum through the mixer and injecting the eutectic-hydride mixture into the aluminum just ahead of the mixer (Figure 4.)

The extruder, as originally designed, was made of cast iron since this material resists the solvent action of molten aluminum better than any other metal available commercially. Metals other than cast iron were considered for the extruder parts. Various alloys with extremely good resistance to chemical attack were tested in molten aluminum. None of these showed promise because of dissolution of some of the alloying elements such as nickel, chromium, and iron. Because of its high carbon content, cast iron is fairly resistant to the action of aluminum. Any iron dissolved away leaves a protective barrier of carbon that prevents further attack. The parts for the extruder were machined directly from cast iron billets. The barrel of the extruder was 6-1/4 inches overall with a bore diameter of 1-1/2 inches. The mixers, patterned after a type used in plastic extruders, were located inside the barrel. The mixers were cast iron cylinders machined to about ten one-thousandths of an inch clearance with the sides of the bore and were about one inch long. Grooves about 1/8 inch thick were machined semi-helically along the length of the mixers.

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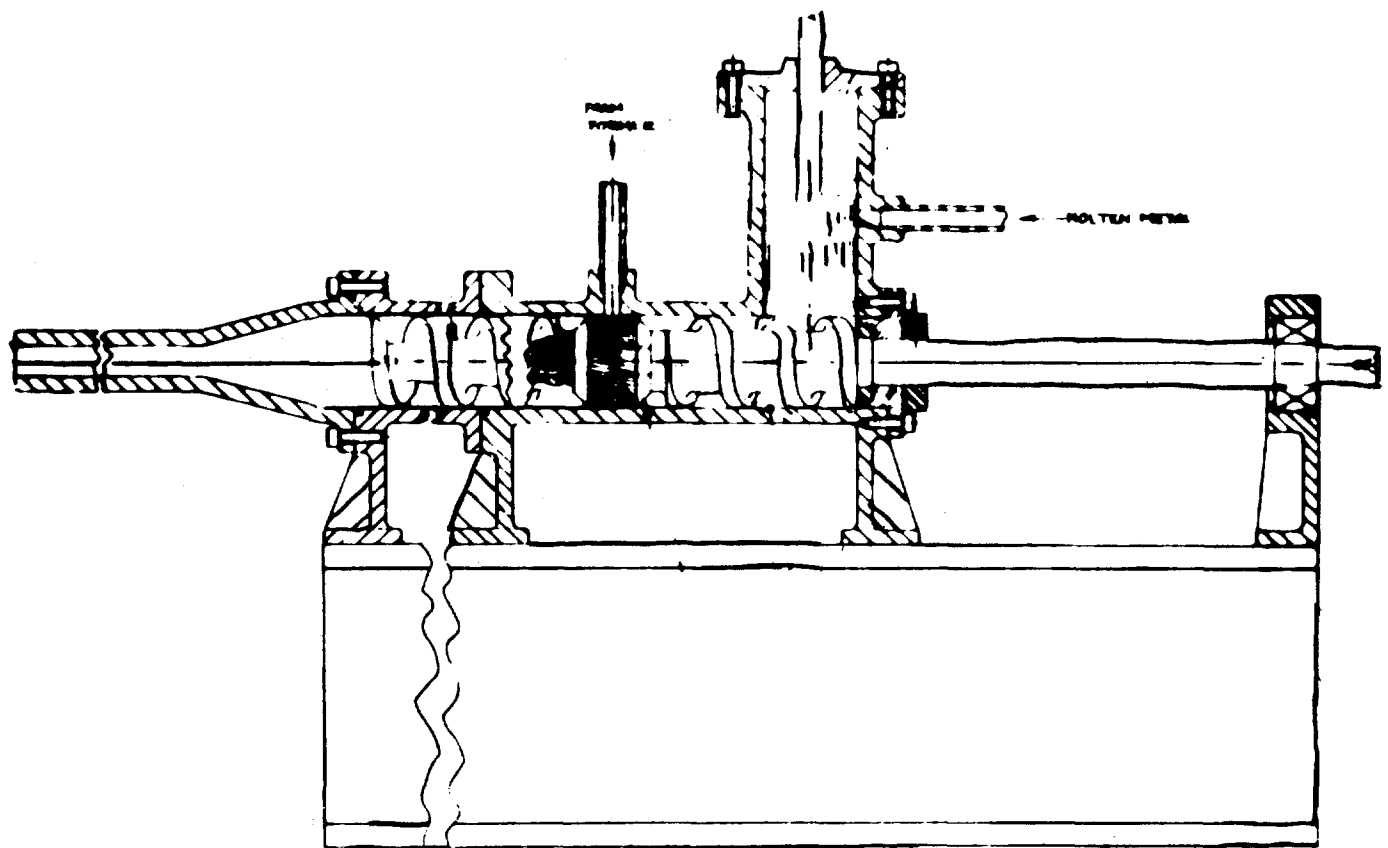


Figure 4. Initial Design of Experimental Extruder for Foamed Metal.

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Originally it was planned to force the aluminum into the extruder by means of a plunger but this method was abandoned in favor of a reservoir and a conduit pipe. Provision was made for the application of pressure with compressed air to drive the aluminum through the pipe, if this was necessary.

The reservoir with a capacity of about 100 pounds of molten metal was made of steel and was coated internally with a protective paint to prevent attack by the molten aluminum. The conduit pipe was attached to the bottom of the crucible with a 1 inch pipe sleeve that had been braced to a 1 inch hole in the bottom. A cover to the crucible was drilled and tapped in the center to accommodate a threaded shaft extending to the bottom of the crucible with a conical end with a 45° taper to fit a corresponding tapered hole in the crucible outlet. This acted as a valve that could be operated by turning the shaft in the threaded cover. The cover was bolted on with a copper wire gasket between the cover and the lip of the crucible to make the system as air tight as possible so that the crucible could be pressurized if necessary. The conduit pipe extending from the bottom of the crucible was just long enough to clear the insulation of the furnace holding the reservoir crucible. A bend was made at this point and a straight length of 1 inch pipe brought the conduit out from under the furnace holding the reservoir. The conduit was then turned down to the extruder. The joint with the extruder was made with a flange gasketed with a sheet of 1/64 inch copper. The flange was for the convenience of disassembly. The extruder was mounted on a length of six inch I-beam. The beam also held the outboard bearing as well as the jack-shaft for speed reduction.

The reservoir crucible was heated in an Amaco Electric Kiln (American Art Clay Co.) which has a heating space of 11" x 14" x 14". The furnace produces temperatures up to 2000°F. and is more than adequate for our purposes. Temperature is controlled with an interval timer, the Temcometer (Thermo Elec. Mfg. Co.). The furnace was turned on its side to make the opening available at the top. It was mounted on cement blocks with openings at the front and sides for access to the conduit pipe. The extruder was mounted on a table at the side of the furnace mounting (Figure 5).

Heating of the crucible was accomplished with the Amaco furnace while the extruder and the conduit pipe were heated electrically with asbestos covered nichrome wire. Induction heating was considered for some parts of the extruder but did not appear feasible.

Power was supplied to the crucible furnace from a 220 volt source and an unsuccessful attempt was made to use a low voltage DC source for heating the conduit. Use was then made of the available 220 and 110 voltage. When the equipment was first heated to around 600°C. a burnout occurred in the extruder heater wiring. To avoid the risk of another burnout, the wiring was removed from the extruder and a furnace constructed around the extruder for the purpose of heating it with an oil burner. This method of heating worked so well that when a burnout occurred in the conduit wiring, conversion to oil heat for this portion was made immediately.

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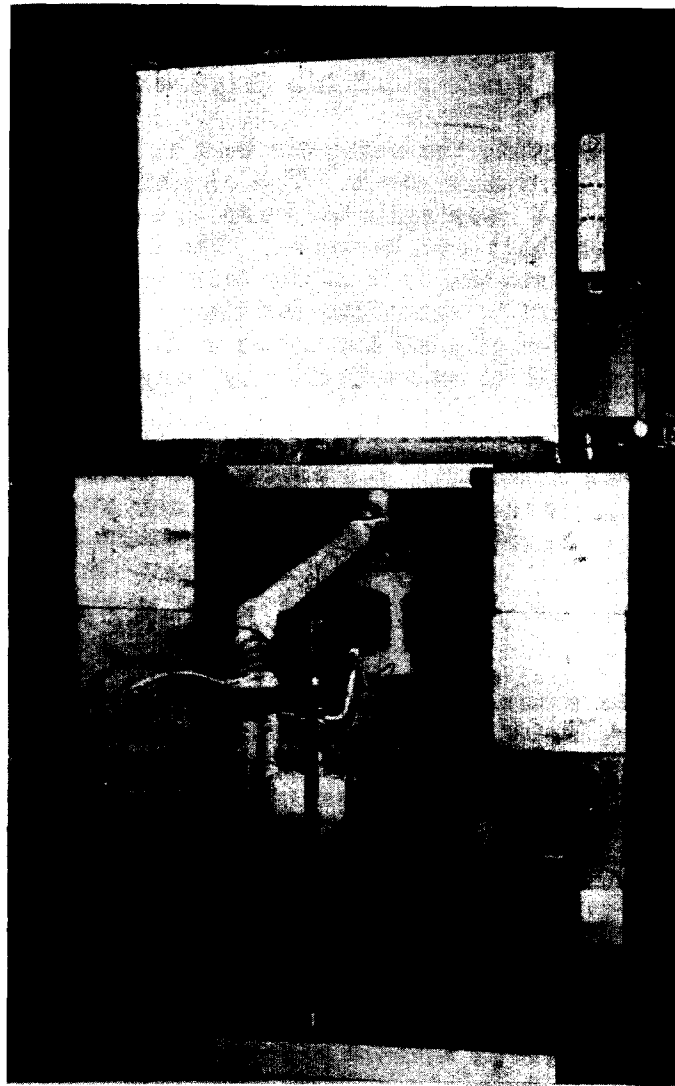


Figure 5. Initial Setup of Equipment for Extruding Foamed Metal. From the crucible in the furnace at the top, the asbestos wrapped conduit in the center leads to the extruder. At the left of the extruder on the I-beam is a water-cooled finned cylinder to protect the outboard bearing from heat conducted along the shaft from the extruder barrel. To the extruder outlet at the right a spreader orifice was later connected.

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Due to space limitations around the extruder and conduit pipe, it was impossible to use any standard pressure oil burner. For this reason, burners were built to fit the space available (Figure 6).

The furnace surrounding the extruder was built of refractory cement reinforced with 1/4 inch hardware cloth. The conduit was enclosed in a 4 inch Transite pipe that had been split for ease of assembly. Both the extruder and the conduit had their own burners. The extruder was heated by blowing the flame directly into the side of the furnace surrounding the extruder and the conduit was heated by directing the flame into the lower end of the Transite pipe and venting directly off the upper end. Heating was entirely adequate. Temperature control was effected by "on-off" operation of the burners.

The flow of molten aluminum was controlled by means of the plug valve in the reservoir as already described. The eutectic-hydride mixture was fed into the extruder through a 1/8 inch pipe attached to the extruder and containing a rotating wood bit to drive the foamer into the extruder. This feeder proved to be too small after a trial run and was removed to make way for a larger feeder.

The mixers in the extruder were rotated at a speed of about 180-200 rpm. The mixing action inside the extruder appeared to be satisfactory. However, on the first run, the mixers bound up due to too little clearance between the mixers and the sides of the extruder barrel. This was corrected by machining the mixers down to about 1/16 inch clearance which prevented jamming of the mixers and permitted adequate mixing.

The next run of the extruder produced about eight to ten cubic inches of foamed metal. The feed of eutectic-hydride mixture in this case was intermittent because the reservoir was not pressurized for these preliminary runs. Thus, some difficulty was encountered in getting the partially foamed metal to flow through the mixers without pressure.

A larger feeder for the eutectic-hydride mixture was constructed by replacing the 1/8 inch pipe previously used with a 1/2 inch pipe. By reaming the pipe to 5/8 inch diameter, a 5/8 wood bit could be used as a screw to drive the foamer.

At this point the reservoir that had contained about 36 pounds of aluminum was emptied. Upon removing the cover and melting the remainder of aluminum in the pot, it was discovered that the portion of conduit extending through the reservoir furnace could not be heated sufficiently and the aluminum had progressively plugged this section of the pipe.

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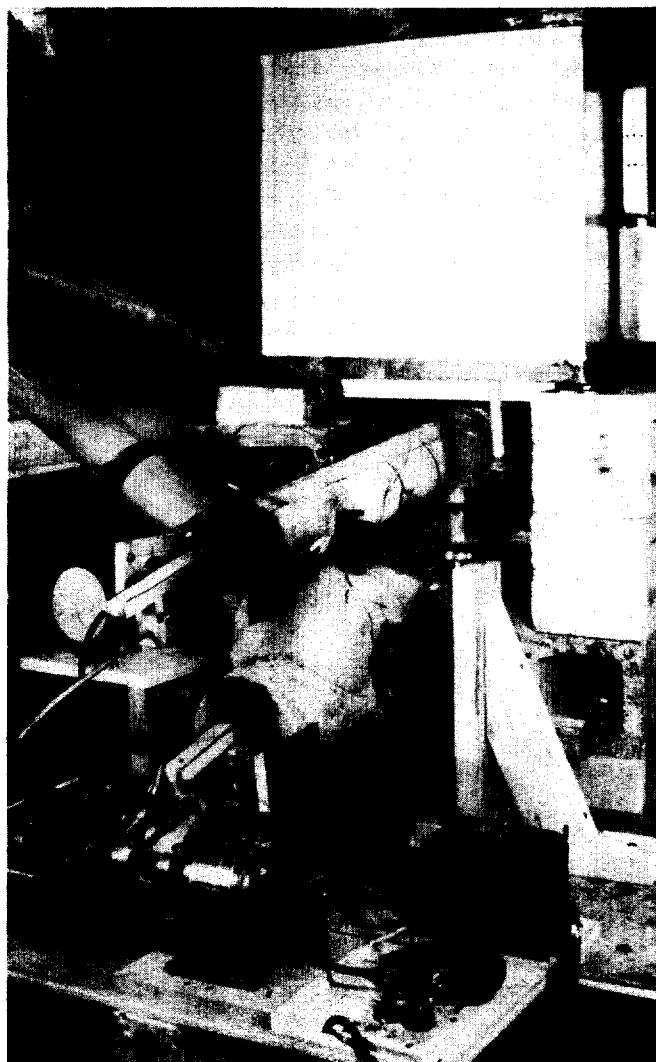


Figure 6. Extruding Equipment Converted to Heating by Oil Burners.

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It became necessary to remove the reservoir and conduit. To avoid repetition of this difficulty, the design and placement of the furnace with respect to the extruder was changed. A new cast iron reservoir was made with the same capacity as the old one. The furnace was remounted to provide adequate working space under the furnace and the extruder was mounted directly under the crucible furnace. This arrangement (Figures 7, 8, and 9) facilitates heating the conduit pipe over its full length since the extruder furnace extends up through the furnace insulation to the bottom of the reservoir, heating over the entire extruder-conduit system. The oil burners have been remodeled so that one switch will control the entire function of the burner instead of manually operated valves and switches as in the older design.

Further work towards improving this equipment is being performed under an extension of this contract.

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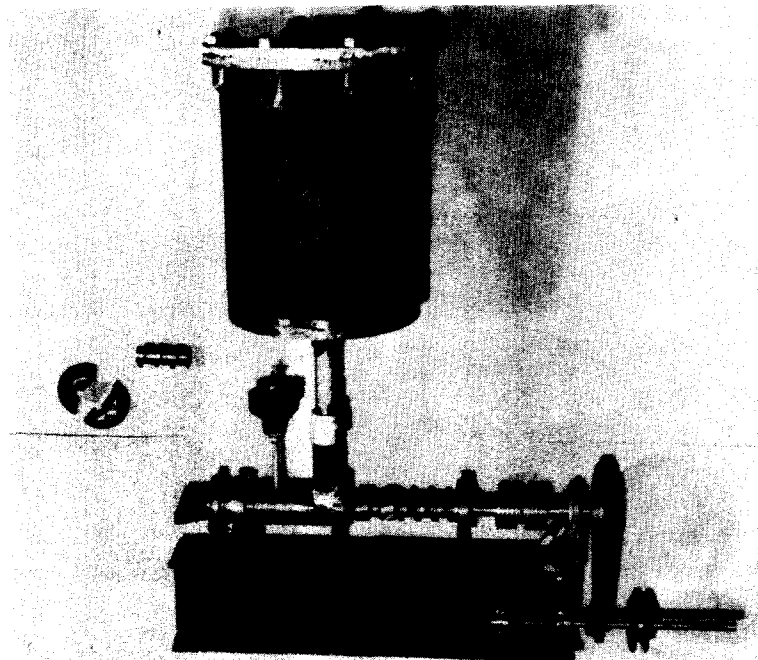
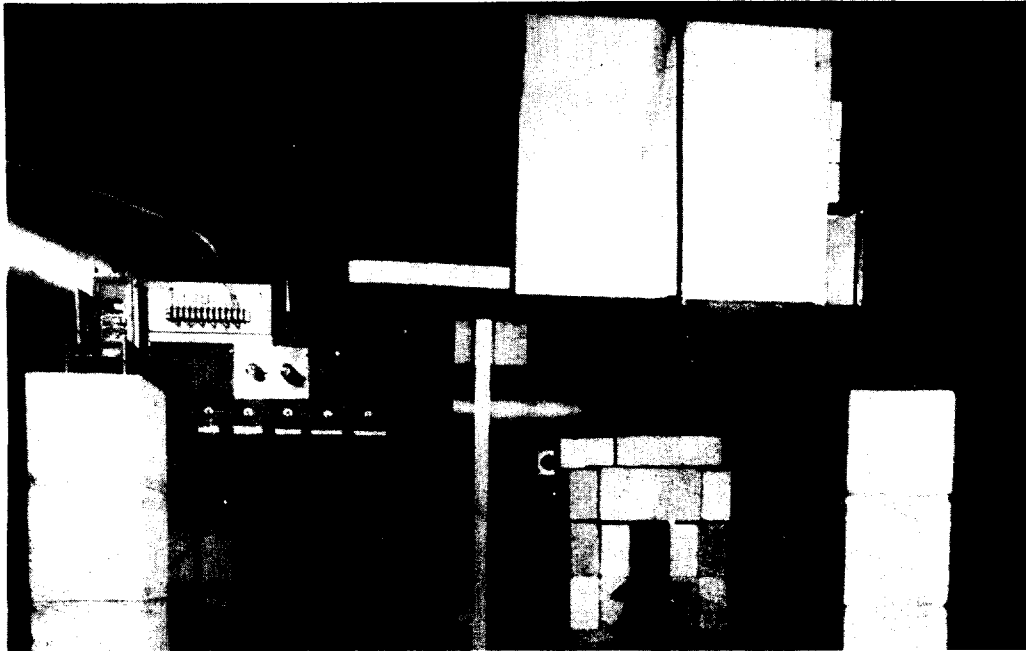


Figure 7. Modified Arrangement of Reservoir and Extruder before Assembly of Reservoir inside Furnace. The Extruder is thus located directly under the crucible furnace.

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**Figure 8. Present Setup of Extruding Equipment
with Extruder Directly under Crucible Furnace.**

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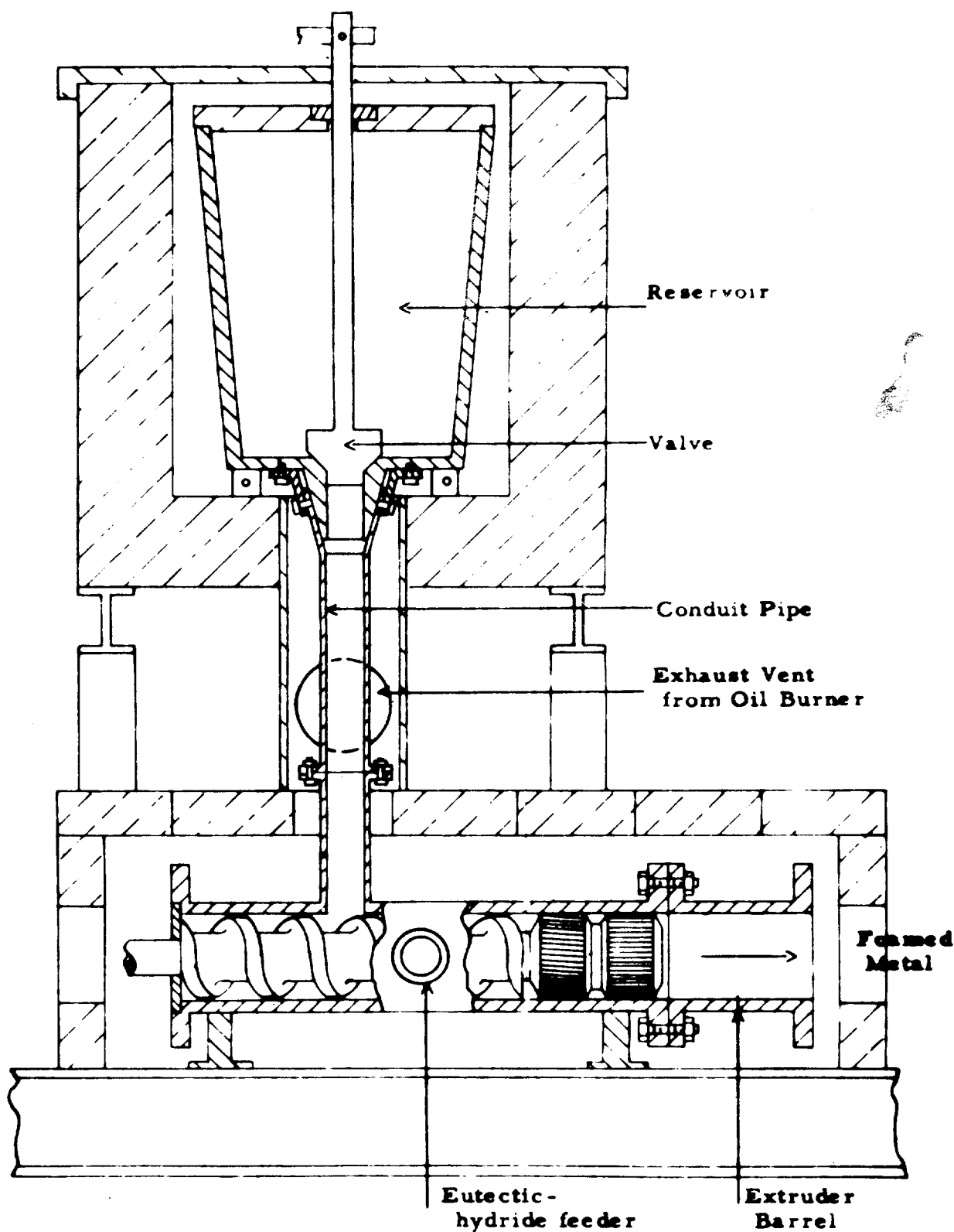


Figure 9. Diagrammatic Sketch of Extruding Equipment of Figure 8.