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HOT-DIPPED TIN-ZINC ON U-0.75 w/o Ti

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ABSTRACT

Conventional Zn galvanizing of U-0.75 Ti results in nonuniform coatings and reduced elongation because of thermal aging of the surface of the U-Ti. A lower melting material which would give sacrificial galvanic protection to the U-Ti was found in the Sn-Zn alloy system. The present work describes: 1) the metallography of the Sn-Zn system, 2) the electrochemistry of the Sn-Zn system with respect to U-Ti, 3) the mechanics of applying a Sn-Zn coating to U-Ti, 4) salt spray corrosion test results of various Sn-Zn alloys applied to U-Ti coupons, 5) mechanical property tests of coated U-Ti tensile bars. An 80 Sn-20 Zn alloy (MP-280°C) was chosen for the galvanizing study because of its lower melting point. The results showed that all alloys of the Sn-Zn system galvanically protected the U-Ti in salt fog environments. The lack of a suitable low temperature flux prevented the operation of the Sn-Zn bath at its optimum temperature and low elongations were obtained with this coating system.

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INTRODUCTION

Galvanizing

Galvanizing is the practice of coating iron or steel with a thin layer of zinc to protect the surface against corrosion. The most important galvanizing method is the hot-dip process, which consists of four steps: surface preparation, fluxing, immersing in molten zinc, and finishing. Surface preparation includes degreasing and pickling operations to remove oil, grease, and scale. The fluxing step is done immediately before immersing the part in molten zinc so that the flux removes any oxide that may have formed on the surfaces since cleaning. Finishing includes removing excess zinc by shaking, draining, or centrifuging; quenching (optional); chromating (optional); and inspection.

The value of zinc galvanizing in protecting U-0.75 Ti was demonstrated in the Air Force GAU 8 penetrator program.[1] The protectiveness afforded to the U-0.75 Ti alloy by galvanized zinc in a hot, moist nitrogen atmosphere is shown in Figure 1. The weight gain curve for the alloy in an uncoated state shows that the corrosion rate was very rapid for the first few days and then changed to a fairly constant, but much slower rate. This dramatic change was partly due to the onset of spallation in the outer layers of uranium dioxide. In fact, the magnitude of this spallation was great enough to produce an overall weight loss of oxide from the penetrator. Figure 1 also shows

that galvanized zinc protected the penetrators from any significant corrosion in the hot, moist nitrogen environment. The weight gains shown for the zinc galvanized penetrators were due to the formation of a white, zinc oxide tarnish film and not to any degradation of the uranium alloy. The corrosion data generated from salt fog tests for uncoated and coated penetrators is shown in Figure 2. The data show that after an extended time period, the zinc began to corrode, but not the uranium alloy.

Two significant limitations on the use of galvanized zinc to protect U-0.75Ti in some applications (such as that presently under consideration) have been uncovered. The first is a lack of tolerance control on coating thickness. Experiments during the Air Force program showed the following:

A single-dip process allowed some of the flux to adhere to the specimen and cause roughness. Dipping the parts a second time in a crucible containing only zinc caused all remaining flux to float to the surface, where it was skimmed before the part was removed. In an attempt to obtain smooth, uniform coatings, galvanized penetrators were initially quenched in either water or mineral oil. Another technique tried was to sprinkle ammonium chloride on the part as it was withdrawn from the galvanizing crucible. Very little benefit accrued from either of these efforts. A slow withdrawal from the zinc bath appeared to produce the smoothest, most uniform coating.

However, this coating was judged to be not adequately uniform and thin enough for the present application.

The second limitation uncovered was that the hold time of one minute in the galvanizing bath (460°C) was sufficient to cause a microstructural and mechanical property change of the surface material of the U-0.75 Ti.[2] This hold time was chosen to ensure that the surface of the part reached bath temperature and to allow the formation of UZn_9 at the alloy surface. It was assumed that the diffusion process would provide a coating with better integrity than one created simply by having the zinc "freeze" on the surface. This change of surface microstructure and mechanical property variance from bulk material is unacceptable for the present application. Thus, zinc-galvanized coatings are not a viable candidate for the present system.

Hot Dipped Tin-Zinc

One solution to the two problems just outlined is to alloy the zinc with a lower temperature eutectic former such as tin. The zinc-tin eutectic is at 198°C.[3] This accomplishes two purposes. First, the lower melting point allows a hot-dipped part to be further processed using hot air devices to smooth and thin the coating. Secondly, the lower melting point permits the dipping pot to be maintained at a temperature well below 460°C. Thus, a change in microstructure and mechanical properties should not occur.

The present investigation included the following studies concerning the hot-dip tin-zinc coating of U-0.75 Ti: 1) The metallography of Sn-Zn system, 2) the electrochemistry of the

Sn-Zn system with respect to U-0.75 Ti which included both rest potential and galvanic current measurements, 3) the mechanics of applying a hot-dip coating to U-0.75 Ti which included an investigation of molten flux, 4) corrosion tests of coated U-0.75 Ti coupons in salt fog, 5) mechanical property tests on coated U-0.75 Ti tensile bars.

METALLOGRAPHY

Figure 3 shows the Sn-Zn binary phase diagram, which is classified as a simple eutectic.[3] The most desirable composition for a coating to be subsequently hot worked after application would be the alloy with the lowest melting point, i.e., near the eutectic composition of 91 Sn-9 Zn by weight. From the phase diagram it is expected that any alloy with a composition rich in zinc compared to the eutectic composition would consist of the eutectic phase plus free zinc. This free zinc should provide the desired sacrificial protection.

Alloys of Sn-Zn were made at ten percent increments by weight over the entire alloy range. As the series of micrographs in Figure 4 show the phases are a mixture of the eutectic phase plus free zinc (identification made by electron microprobe analysis). The amount of eutectic and free zinc follows the binary lever rule very accurately.

ELECTROCHEMISTRY

Corrosion Potential Measurements

The corrosion potential of each of these alloy compositions was measured in a 10^{-2} molar potassium chloride solution. The

results are shown in Figure 5. It is apparent that the free zinc in the microstructure of the alloys is the dominant species in determining the corrosion potential of the particular alloy. As tin is added and the composition of the alloy approaches the eutectic point (91 Sn-9 Zn), the corrosion potential does shift towards that of pure tin but only a small percentage of the composition change. Thus even at a composition of 90 Sn-10 Zn (a one percent excess of zinc over the eutectic composition) the corrosion potential is still most closely to that of pure zinc. The significance of these results is that any composition of a Sn-Zn alloy which has free zinc is electronegative with respect to the U-0.75 Ti alloy and a coating of this material should behave in a sacrificial manner towards U-0.75 Ti. Thus, any of these compositions could be used as a replacement for the pure zinc coating.

Galvanic Current

A kinetic measurement was made to verify the thermodynamic predictions obtained from the corrosion potential measurements. In this type of test, an electrical couple of Sn-Zn alloy and U-0.75 Ti were tested in a KCl electrolyte. The arrangement of the couple and associated monitoring equipment are shown schematically in Figure 6. Upon submersion of the couple into the electrolyte, a flow of metal ions into solution is accompanied by a movement of electrons through the electrical circuit. The magnitude and direction of this electron flow, or corrosion current, is recorded as a function of time. An example of the

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was a mixture of re
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and $ZnCl_2$; the percentages being 46.4 KCl
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The mechanical
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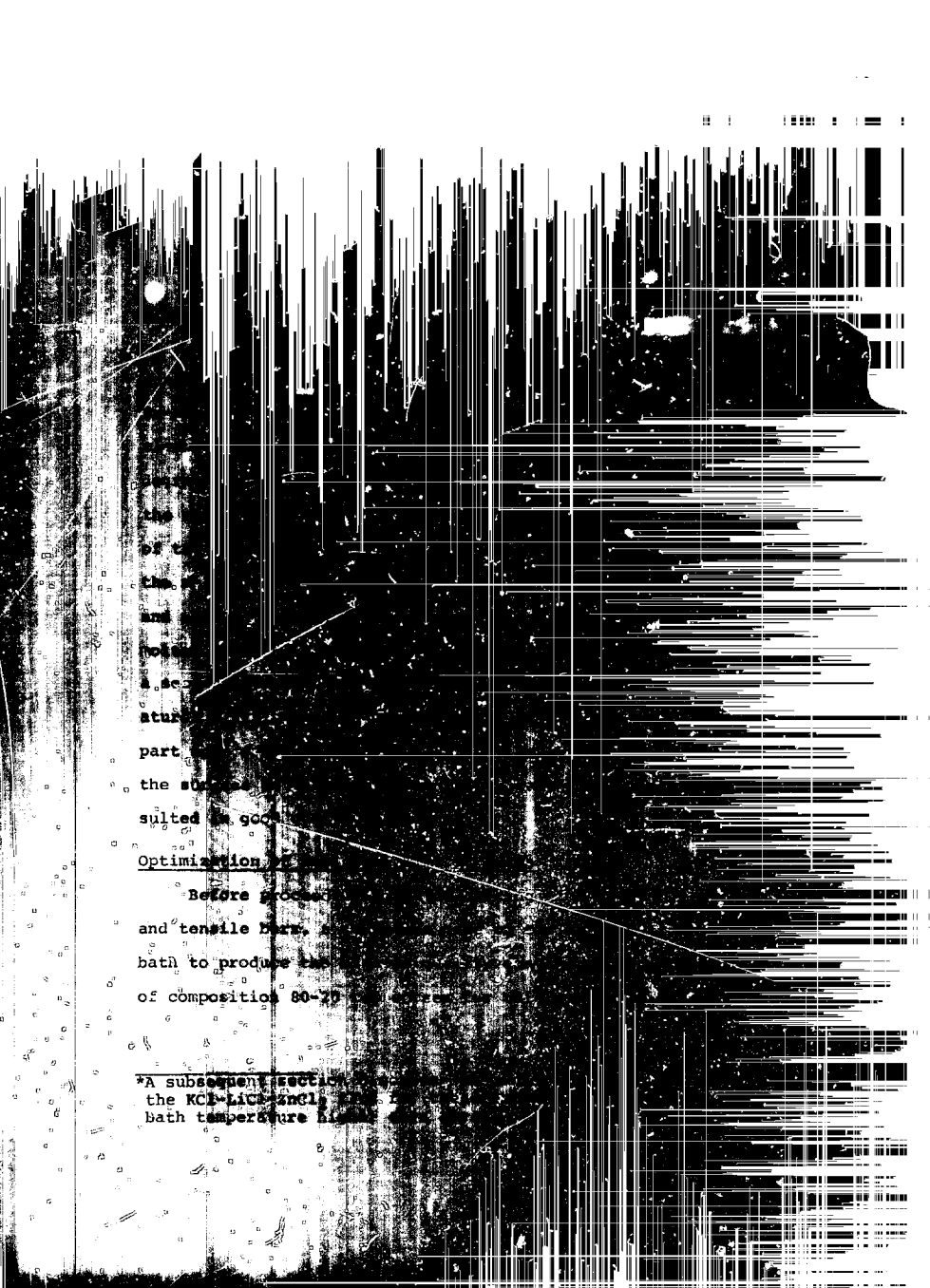
*du Pont Trademark



*A subsequent section
the KCl-LiCl-ZnCl
bath temperature

times for each step (1st dip, 1st dip and 2nd dip) are given in Table II. [illegible] was based on visual observation and [illegible]. It was selected as being procedure #[illegible], that is, flux time 60 sec., dip 1 [illegible] sec. and dip 2 - 15 [illegible]. It was found that less flux time did not permit adequate [illegible] and it took approximately [illegible] seconds for [illegible] to reach [illegible] temperature and be [illegible] the flux processed at [illegible] which [illegible]. A [illegible] which did not [illegible] to the U-0.75 Ti and [illegible]. A time of [illegible] seconds [illegible]. Additional cold time [illegible] caused of either forming too [illegible] which is brittle, or of [illegible] of the surface through heat [illegible] and to be very useful in improving [illegible] coating. It tended to thin the coating a[illegible] time was best. Increasing the residence [illegible] bath caused an unwanted growth and roughening [illegible].

Investigation of Hot-Working Techniques

Straight cylinders made from U-0.75 Ti which were 4 inches long by 0.62 inches in diameter were used to investigate techniques for warm-working the coating after application. The

80 Sn-20 Zn alloy was again selected for these experiments and the coating procedure employed was that discussed as optional in the preceding section.

The initial direction of the warm-working technique was to mount the coated cylinder in a lathe and impinge upon the spinning surface a horizontally moving hot-air jet. A chamber was built which contained stainless steel tubing and inserted into a resistively heated tube furnace capable of attaining 1100°C. The gas in a position within the exit tube was measured to have attained a temperature in excess of 900°C at the flow rates judged necessary for coating movement. Unfortunately the temperature of the gas measured at the surface of the part was approaching 350°C at best and did not contain enough heat content to heat the surface of the U-0.75 Ti, in addition to melting the coating, to allow the excess Zn to be spun off. At this point, the approach utilizing warm-air devices was abandoned.

The next approach tried in an attempt to strip excess zinc from the cylinders was to use an oxy-acetylene torch as the heat and gas source. The experimental setup was similar to those just described. Briefly, a zinc coated cylinder was spun on a lathe while the flame from the torch impinged upon the surface. The flame was slowly traversed along the axis the cylinder. This approach was successful in melting the zinc and expelling it from the surface. However, the resultant surface finish was unacceptally rough, the topography appearing as waves on an ocean. Apparently what caused this surface

morphology was the removal of zinc by means of individual droplets. The surface tension of the zinc in forming the droplets left behind the peaked or waved appearance upon droplet removal. If this explanation is correct, it has serious implications concerning the removal of excess zinc by post-dipping techniques. These types of approaches were suspended at this time.

An experiment was then designed where an attempt would be made to remove the excess zinc immediately upon removal of the part from the molten zinc pot while the coating was still liquid. A previous experiment utilizing a centrifuge was used as a guide. In this case, a drill press would be used to hold the cylinder in a vertical position. By means of the associated lever, the part could be lowered and raised in the molten flux and zinc pot in a controlled manner. Most importantly, the part could also be rapidly spun, upon removal from the pot, by means of the torquing motor. This approach gave promise for good control of both the hot-dip step and the spin removal of zinc.

Equipment was being assembled to try this experiment when results from mechanical testing caused a halt in the hot-dip approach to coating. This will be explained in detail shortly in the "Mechanical Test" section of this report.

CORROSION TESTS

Previous corrosion tests done to evaluate the effectiveness of coatings in protecting uranium have demonstrated that a

salt fog test is a good discriminator. This is particularly true when the coatings of interest are metallic. Other environments classically used for corrosion studies involving uranium are moist air or moist nitrogen at moderately elevated temperatures. These two environments, and particularly moist nitrogen, are best for relative evaluation of uncoated materials such as discriminating the effect of aging on corrosion response. In addition, moist nitrogen is a good environment for evaluating organic coatings such as paints on uranium. However, for metallic coatings, these environments are usually too benign to discriminate between coatings other than the most unacceptable. The salt fog test was thus used for this investigation.

The salt fog test is a standard test, the details of which are given in MIL-STD-810B, Method 109. It basically consists of a salt fog atomized from a 5 weight percent sodium chloride solution which is maintained at 35°C. The total time specimens were subjected to this test was 16 days. The samples were removed, cleaned and weighed every two days throughout the duration of the test.

Two sets of coated specimens were tested in the salt fog. Both sets consisted of uranium coupons coated with the series of tin-zinc alloys discussed previously. The first set was tested in the "as hot-dipped" surface condition. The second set was designed to test the galvanic protectiveness of the coatings when flaws in the coatings were present. The flaws were intentionally introduced by drilling through the coating at five

positions with a 0.010" diameter drill bit. Although the surface area of uranium exposed by this procedure was not large, it was sufficient to both visually and quantitatively measure the effect upon corrosion response.

The results from these salt fog tests are shown in Figures 8 and 9 for the two sets of coupons, respectively. Figure 8 shows that the corrosion response of the tin-zinc alloy series is dependent upon zinc content, as was expected. The higher the zinc content, the greater the corrosion. The reason being that the amount of free zinc is proportional to the corrosion response of the tin-zinc or eutectic-zinc alloy. It should be emphasized that the corrosion response measured was for the coating, not the uranium coupon. In no case was there observed any corrosion of the uranium in this set.

This result is further emphasized in the results from the second set (the set containing the induced flaws) shown in Figure 9. If the flaws did not affect the corrosion response, the weight changes should be similar to the first sample set and proportional to the zinc content of the alloy coating. Indeed, this was found to be true. Figure 9 shows results very similar to Figure 8 for the respective alloy coatings. Thus, all the coatings did galvanically protect the bare U-3/4 Ti at the flaws as was expected from the previously discussed electrochemical measurement data.

In conclusion, from the corrosion test results, any of the tin-zinc alloy coatings will adequately protect the U-3/4 Ti substrate, even when the coating is flawed. Considering also

the case of zinc chromating and base corrosion rate of the coating itself, still makes the 80 Sn-20 Zn alloy the preferred choice.

MECHANICAL TESTS

Hydrogen embrittlement is the main material property of concern when using U-0.75 Ti in an application which requires mechanical strength and some ductility of the part after prolonged storage. A U-0.75 Ti part manufactured with close quality control and all heat treating steps done in a good vacuum will exhibit a ductility level in excess of 16 percent elongation and 20 percent reduction in area along with reasonable ultimate tensile strength, 1380 MN/m^2 (200 Ksi). This material will have a hydrogen content below one part per million, ppm. However, if the heat treating is done in salt baths or molten lead pots, the hydrogen level is increased and the ductility can be reduced to as low as two percent, in spite of maintaining good strength. The hydrogen level can climb as high as 12 ppm.

Figure 10 shows the effect on ductility of an increasing hydrogen content in a typical, heat-treated U-0.75 Ti part. It is important to note the serious detrimental effect that a small amount of hydrogen has on the ductility. Thus, if the part needs to exhibit ductility, the hydrogen content must be kept low during manufacturing.

Hydrogen must also be prevented from entering the U-0.75 Ti component during its storage lifetime. There exists data from two different studies and investigators which strongly

suggest that when U-0.75 Ti is stored in an environment which permits an interaction with water vapor, the ductility is decreased. The first evidence is summarized in Table III. It is clear that exposing U-0.75 Ti to moisture caused a ductility decrease. The data tabulated in Table IV also shows this correlation of degradation in ductility response in U-0.75 Ti after exposure to water vapor. In addition, the information in Table IV also shows that the two most commonly used coatings on uranium and uranium alloys, (electroplated nickel and electroplated nickel-zinc), not only do not prevent the degradation in ductility but actually appear to accelerate the degradation.

A third study indicates that the reason for the ductility loss of U-0.75 Ti after exposure to moisture is the introduction of hydrogen into the alloy as a result of corrosion. The uranium plus water reaction results in the formation of uranium dioxide and the production of hydrogen. Thus written:

$$U + 2\,H_2O \rightarrow UO_2 + 2\,H_2$$

It is possible for some of the liberated hydrogen to absorb and then diffuse into the U-0.75 Ti. Table V gives the hydrogen profile measured in an U-0.75 Ti specimen which had been electroplated with nickel and then exposed to a salt-fog environment. Clearly, if these quantities of hydrogen are diffusing into the material as a result of the metal-water interaction, then it is understandable that there results a significant ductility loss in the material. Testing U-0.75 Ti specimens in a similar manner but in a less aggressive environment resulted in analogous

behavior but to a less severe degree. In summary, the extent of metal-water reaction and thus the extent of hydrogen embrittlement and ductility loss is a matter of kinetics which is governed by the severity of the corrosive environment.

There is one additional problem concerning the association of water vapor and U-3/4 Ti. This is the observed degraded response of U-0.75 Ti tensile specimens or parts when subjected to deformation in the presence of water vapor. The degree of the degradation in response (primarily a loss in ductility) is directly related to an increased water vapor or relative humidity level. In fact, at a relative humidity level of 100%, the material behaves in a brittle manner exhibiting elongation as low as two percent. In addition a coating system has not been found which prevents this response from occurring in humid environments.

The purpose of the presently reported mechanical tests then was to evaluate the effectiveness of a tin-zinc alloy coating in preventing both or either the loss in ductility of U-0.75 Ti in moist test environments or the loss in ductility due to hydrogen embrittlement caused by exposure of U-0.75 Ti to moist environments.

The design of the U-0.75 Ti specimen is shown in Figure 11. It is a standard, round, tensile specimen. The tin-zinc alloy chosen for testing in this section was the 80 Sn-20Zn composition. The application technique used was that found to be optimum as described in an earlier section. A half dozen of the tensile

specimens were coated for an initial evaluation. Some additional specimens were tested in an uncoated state for comparison and standardization.

Table VI lists the results from this set. The bare or uncoated specimens responded as predicted. A bare specimen tested in vacuum with no simultaneous nor previous exposure to moisture exhibited excellent mechanical properties (i.e., ultimate strength above 1380 MN/m^2 (200 Ksi) and ductility greater than 16% elongation). Conversely, a bare specimen tested in a 100% R.H. environment exhibited good strength but extremely brittle behavior (i.e., UTS of 1520 MN/M^2 (220 Ksi), Elong. of 2.5%).

The two specimens coated with the 80 Sn-20 Zn alloy and tested in the 100% R.H. environment did not exhibit a ductility level significantly better than the bare specimen; their ductilities being respectively 3.0 and 3.6 percent compared to 2.5% for the bare specimen. The probable explanation for this result is that the Sn-Zn alloy coating did not galvanically protect the U-0.75 Ti specimen from water vapor degradation at flaws in the coating, of which there are always some present. The tin-zinc coating was a disappointment from the standpoint of preventing brittle behavior of U-0.75 Ti tested or deformed in the presence of moisture.

Two more specimens coated with the 80 Sn-20 Zn alloy were tested, but in a vacuum rather than moist environment. Surprisingly, they exhibited a ductility level significantly lower than the bare specimen tested in vacuum; the ductilities being 7.6 and 9.8 compared to 18.3 percent, respectively. The

obvious suggestion by this result is that the coating or the procedure used to apply the coating is affecting the mechanical properties of the U-0.75 Ti alloy.

In order to obtain additional information concerning the cause of the ductility loss, a specimen was coated using the same procedure as those preceding with the exception of a doubled hold time in the molten tin-zinc bath, which is at 515°C. The mechanical response of this specimen is also listed in Table VI as specimen number 7. The important result is that the ductility measured for this specimen was only 3.8%. This confirms the hypotheses that either the coating or the coating procedure is affecting the U-0.75 Ti. However, since the coating is essentially the same for specimen numbers 5, 6 and 7 (only the thickness of the coating being greater for 7), the procedure seems more suspect than the coating. In particular, the temperature excursion of the surface of the specimen is suggested as the cause.

A final specimen was prepared to address this question. It was subjected only to the soak in the molten flux at 515°C for a total submersion time of 45 seconds. The surface of the specimen was at the temperature of 515°C for approximately 15 to 20 seconds. The specimen was removed from the flux and rinsed with water thus quenching the metal and removing the flux. After sufficient drying of the surface, the specimen was tested in vacuum. The mechanical properties of this specimen are listed in Table VI for specimen number 8. The resultant strength was excellent (1560 MN/m^2, 226 Ksi) but a ductility response of 5.6% elongation

is significantly less than the value of 18.3 for untreated, uncoated U-0.75 Ti. The cause of the ductility loss is obviously due to the coating procedure and not the coating itself, since no coating was put on this specimen.

There are two aspects of the fluxing procedure which may account for the produced ductility loss. They are an etching or roughening of the specimen surface and a temperature excursion of the surface. A surface roughening could introduce a surface flaw with accompanying reduction in fracture toughness and loss in ductility. This event has been observed for specimens electroplated with nickel which have undergone a severe chemical etch as part of the coating procedure. However, this reduction in ductility has been measured as an approximately one percent drop in the value for elongation. The data is shown in Table IV. This explanation does not account for a reduction of approximately 14% in elongation. The most probable explanation for the cause in the ductility loss is that the temperature excursion to 515°C of the specimen surface has produced an aging effect upon this material which strengthens it while also decreasing its ductility. Since numerous experiments have shown the sensitivity of the ductility response of U-0.75 Ti tensile specimens to their surface condition, it is not surprising that in the present case the ductility loss is appreciable.

The processing direction to be pursued, which is expanded upon in a following section, is to eliminate this temperature excursion.

SUMMARY

- The tin-zinc phase diagram is a "simple-eutectic" type with the eutectic composition at 91Sn-9Zn by weight.
- The 80Sn-20Zn composition is composed of eutectic phase plus free zinc.
- The corrosion potential of the 80Sn-20Zn composition is close to that of zinc and electronegative with respect to the U-0.75 Ti alloy.
- An alloy button of 80Sn-20Zn electrically connected to a coupon of U-0.75 Ti in a salt electrolyte produced a negative corrosion current, i.e., the Sn-Zn corroded sacrifically and protected the U-0.75 Ti.
- The molten flux used was a mixture of KCl, LiCl and $ZrCl_2$.
- The hot-dipping procedure was to submerse the part in molten flux until the surface was clean, submerge the part in molten Sn-Zn until the coating was complete, withdraw part and submerge in second pot containing only Sn-Zn for a few seconds.
- The warm-working technique of mounting the coated cylinder in a lathe and impinging upon the spinning surface a horizontally moving hot-air jet was not satisfactory.
- Removing excess alloy coating from the part is best done while the coating is still molten after the dipping.
- A salt fog test is a good discriminator to evaluate the relative effectiveness of metallic coatings in protecting uranium from corrosion.
- Results from the salt fog tests demonstrated that any of the

tin-zinc alloy coatings will adequately protect the U-0.75 Ti, even when the coating is flawed.

- Results from salt spray tests also showed that corrosion rates of the alloy coatings increased with increasing zinc content.
- The tin-zinc [illegible] as the coating which maximized both corrosion resistance and sacrificial protection was the 80Sn-20Zn.
- Mechanical test results on tin-zinc coated U-0.75 Ti showed that the coating did not prevent embrittlement of the U-0.75 Ti when tested in a humid environment.
- Furthermore, mechanical test results indicated that the coating process itself was producing an embrittlement in the U-0.75 Ti.
- The cause of the embrittlement was determined to be due to the temperature rise of the U-0.75 Ti surface upon hot-dipping which produced an aging of the surface material.

FUTURE DIRECTION

The parameter which most likely is the cause of the ductility loss in hot-dipped, metal coated U-0.75 Ti tensile specimens or parts is the temperature excursion above 500°C. The thrust of future efforts should thus be directed at significantly lowering the maximum temperature of exposure. An alloy of tin-zinc, particularly 80 Sn-20 Zn, reduces the molten-metal bath temperature, to approximately 300°C, from that of 450°C for zinc alone. Thus, the 80 Sn-20 Zn alloy and the 300°C bath temperature should be a good coating applied at a low enough temperature to not effect the U-0.75 Ti.

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not work. The LiCl content was too low to produce proper etching and cleaning of the U-0.75 Ti surface. Apparently the LiCl content must approach 40% before an effective mixture is obtained. For the $LiCl-ZnCl_2$ system, a 40% LiCl-60% $ZnCl_2$ mixture would have a melting point of approximately 400°C.[5] This may be a marginal temperature with respect to the effect on mechanical properties. This flux was not tried for either coating or property effects. It may work. If it does not, another approach to this problem must be considered.

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TABLE I

Mechanical Properties of Zinc-Galvanized U-0.75 Ti Tensile Bars

Surface Treatment	Test Environment	Yield Strength MN/m^2	Yield Strength KSI	Tensile Strength MN/m^2	Tensile Strength KSI	Elongation
As-machined	60% R.H.	993	144	1441	209	8.3
Zn-galvanized	60% R.H.	966	140	1407	204	9.5
As-machined	100% R.H.	986	143	1428	207	8.8
Zn-galvanized	100% R.H.	952	138	1449	210	5.0

Data from Reference 1

TABLE II

Matrix of Times for Coating Optimization Study

Procedure No.	Flux Time sec	Dip 1 Time sec	Dip 2 Time sec
1	60	30	30
2	60	45	30
3	60	60	30
4	60	30	15
5	60	45	15
6	60	60	15
7	90	30	--
8	60	30	30
9	60	30	--
10	60	45	--
11	90	15	30
12	90	15	15
13	90	15	--
14	60	10	--

TABLE III. Mechanical Properties of U-0.75Wt% Ti Sheet Tensile Specimens After Exposure to Environment at 75°C+

Exposure Environment	Test Time (days)	Yield Stress* (ksi)	Yield Stress* (MN/m^2)	Ultimate Tensile Strength (ksi)	Ultimate Tensile Strength (MN/m^2)	Elongation (%)
Vacuum	14	137	945	216	1490	12.6
Wet O_2	14	146	1010	207	1430	6.7
Wet N_2	14	136	938	199	1370	5.1

+ Data from N.J. Magnani, Sandia Laboratories, Albuquerque, New Mexico.

* Tests performed at R.T. at strain rate of 0.03 min^{-1}, average of three tests.

Table IV. Ductility Data for U-0.75 Ti Tensile Specimens After Exposure to Moist Nitrogen at 75°C[+]

Specimen Surface Condition	Ductility
Bare, As-Machined (No Environmental Exposure)	20.5
Ni-plated (No Environmental Exposure)	19.5
Ni-Zn plated (No Environmental Exposure)	19.5
Bare, As-Machined	14.0
Ni-plated	8.0
Ni-Zn plated	9.0

[+] Data from H.R. Johnson, Sandia Laboratories, Livermore, California.
Corrosion Test - 20% R.H. nitrogen at 75°C for 30 weeks.
Tensile Test - 0.005 inch per second strain rate.

Table V. Profile of Hydrogen in Corroded U-0.75 Ti*

Position from Surface (in)	Hydrogen Level (wppm)
1/16	26 ± 2
1/8	22
3/16	17
1/4	12
5/16 - Center	12

* Data from L.J. Weirick, Sandia Laboratories, Albuquerque, N

Ni-plated
Salt Fog -10 Days

+ Vacuum fusion analysis

TABLE VI

Mechanical Properties of U-0.75 Ti Tensile Specimens with Coatings of Zinc-Tin

Specimen No.	Surface Treatment	Test Environment	Yield Strength		Tensile Strength		Elongation
			MN/m^2	Ksi	MN/m^2	KSI	
1	bare	1μ Vac	1000	145	1553	225	10.3
2	bare	100% R.H.	1021	148	1525	221	2.5
3	80Sn-20Zn	100% R.H.	1049	152	1539	223	3.0
4	80Sn-20Zn	100% R.H.	1035	150	1553	225	3.0
5	80Sn-20Zn	1μ Vac	1049	152	1615	234	7.6
6	80Sn-20Zn	1μ Vac	1014	147	1608	233	9.0
7	80Sn-20Zn*	1μ Vac	1035	150	1518	220	3.0
8	flux etch	1μ Vac	1056	153	1500	226	5.0

*held twice the optimum time in the Sn-Zn bath

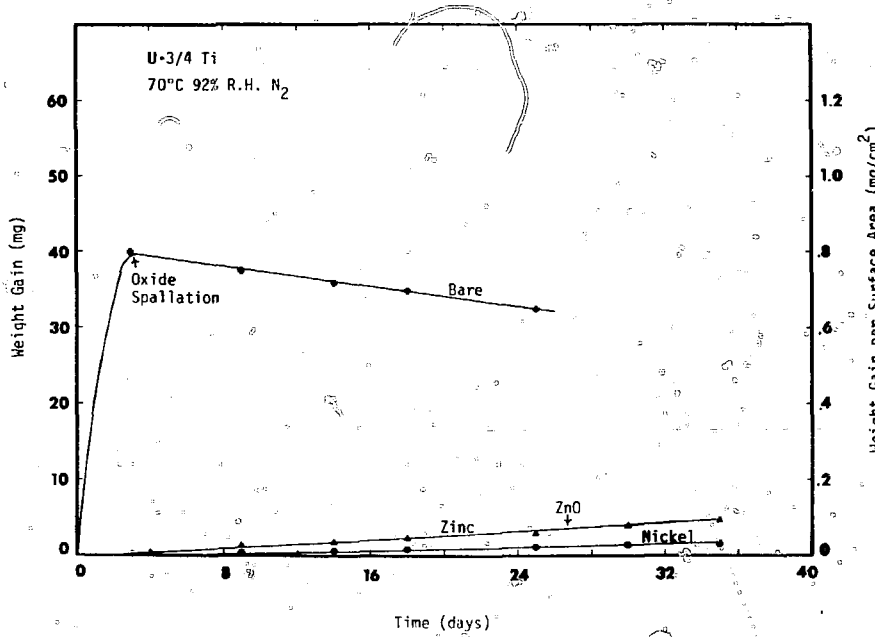


Figure 1. Corrosion and Relative Protection of U-3/4 Ti Penetrators in 92 Percent R.H. Nitrogen at 70°C

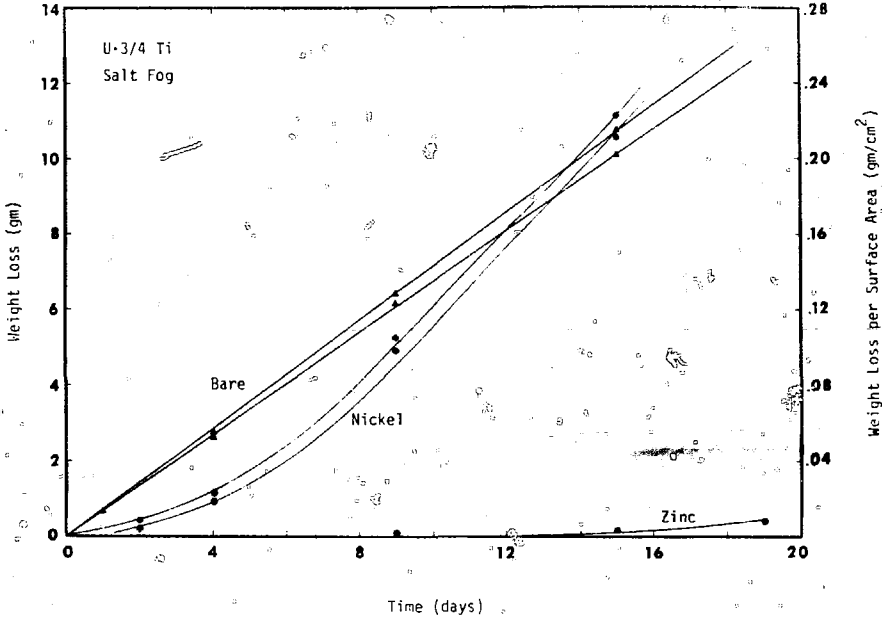


Figure 2 . Corrosion and Relative Protection of U-3/4 Ti Penetrators in Salt Fog at 35°C

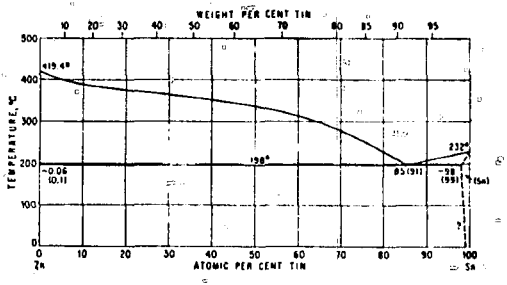


Figure 3. Zinc-Tin Phase Diagram

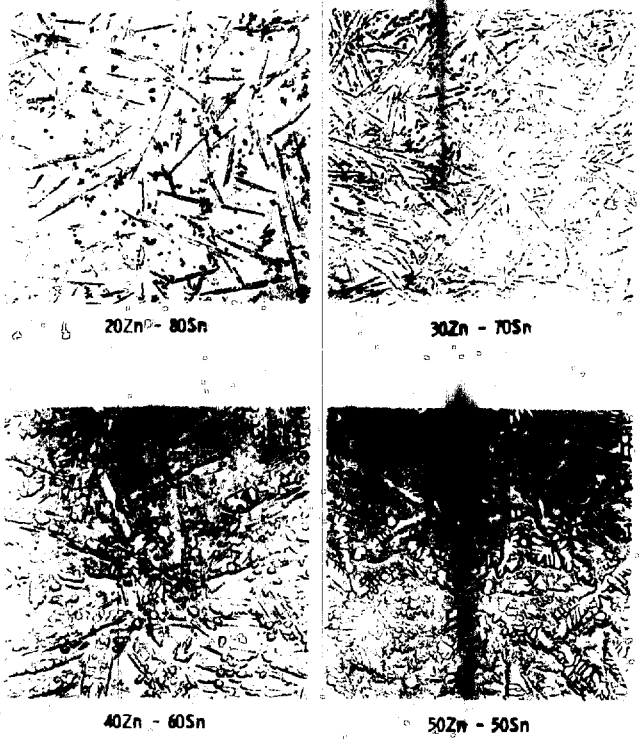
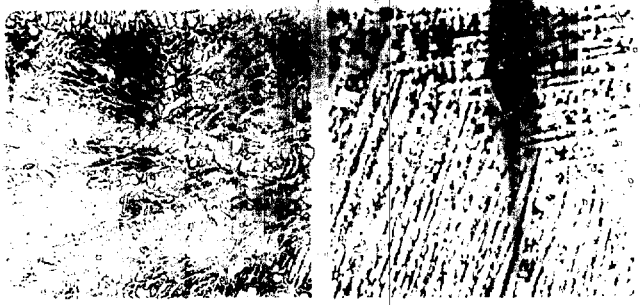
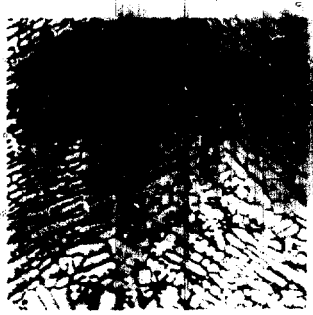


Figure 4. Microstructure of Zinc-Tin Alloys

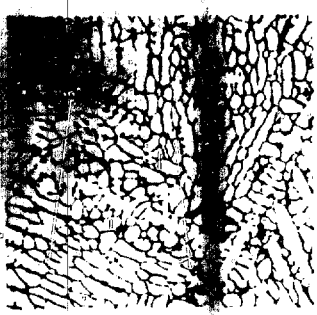


60Zn - 40Sn

70Zn - 30Sn



80Zn - 20Sn



90Zn - 10Sn

Figure 4. (continued)

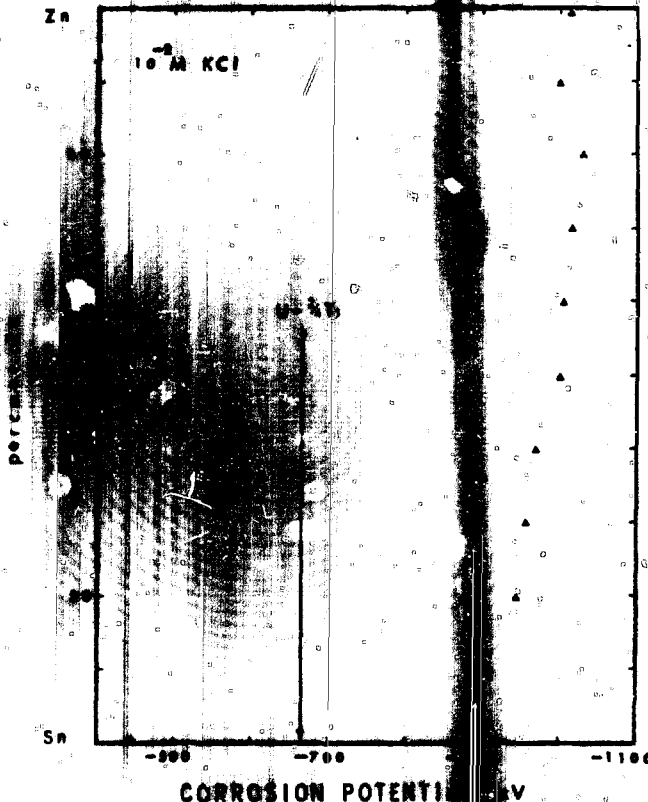


Figure 5. Corrosion Potential of Zinc-Tin A 10^{-2} M KCl

VOLT

TEFL

GL

COA

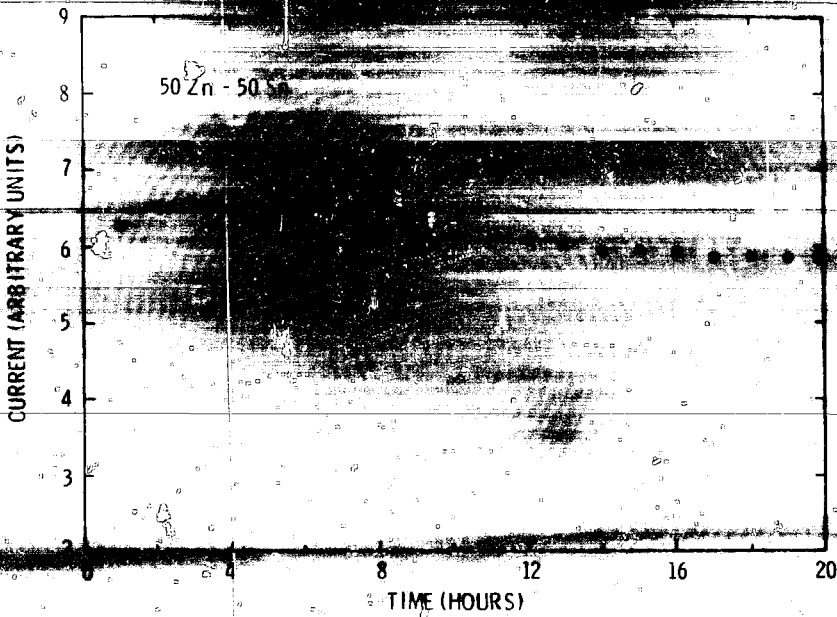


FIGURE 7. Corrosion Current of U 0.75 Ti - Coating Material Galvanic Couple.

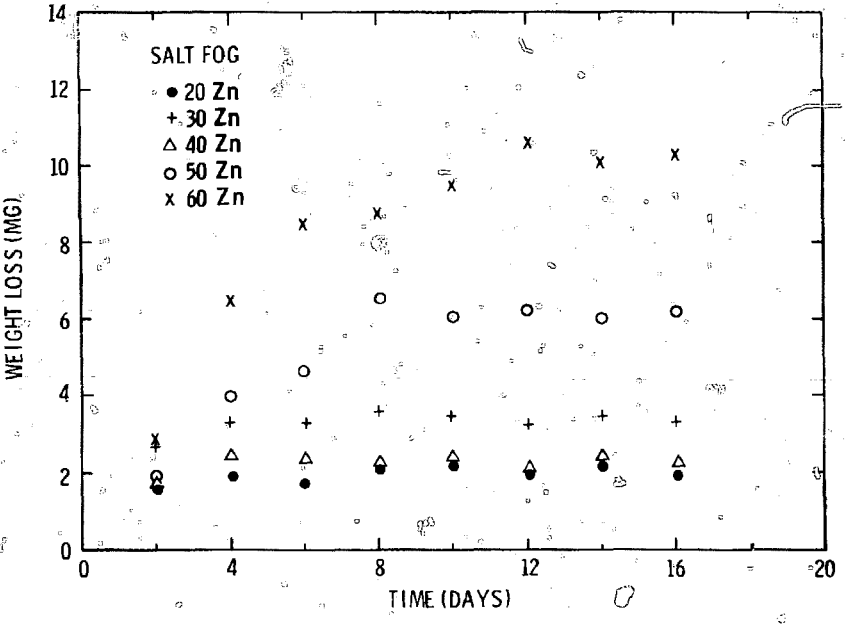


FIGURE 8. Weight Loss of Zinc-Tin Coated X-0.75 Ti Coupons in Salt Fog.

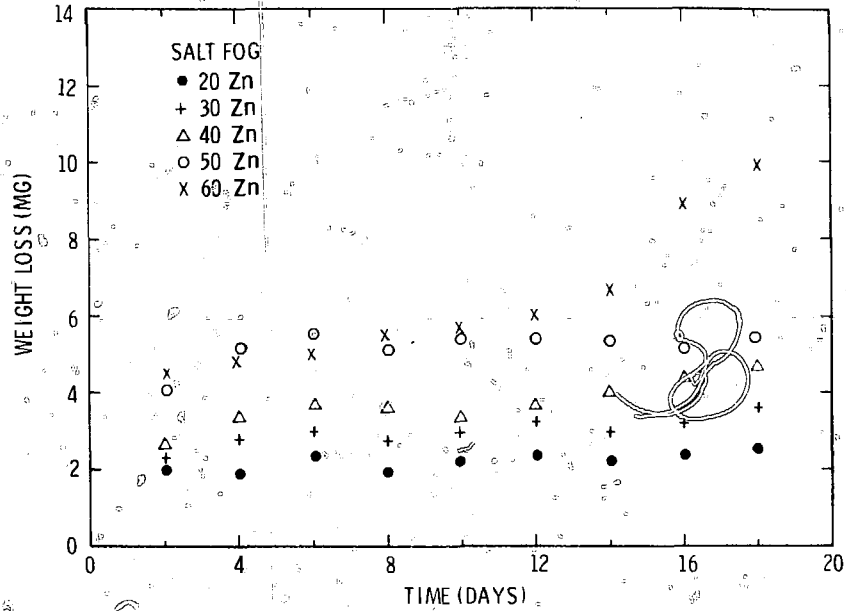


FIGURE 8. Weight Loss of Coated U-0.75 Ti Coupons Containing Flaws in Salt Fog.

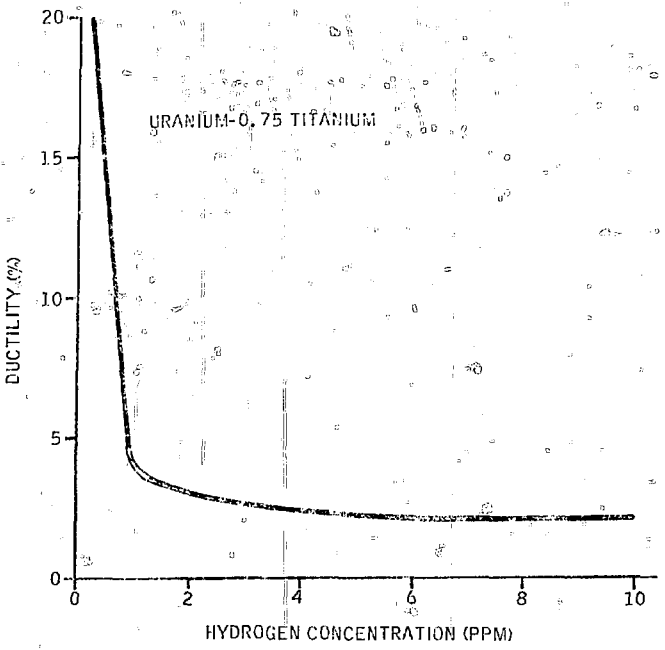

URANIUM-0.75 TITANIUM
DUCTILITY (%)
HYDROGEN CONCENTRATION (PPM)
20
15
10
5
0
0
2
4
6
8
10

FIGURE 10.

ES:

THE REDUCED SECTION SHALL BE CONCENTRIC WITH THE PITCH DIAMETER OF THE THREADED ENDS WITHIN [illegible]

THE REDUCED SECTION SHOULD BE TAPERED FROM THE CENTER TO THE ENDS WITH THE DIAMETER OF THE ENDS A MAXIMUM OF .002 LARGER THAN THE CENTER.

FINISH THE REDUCED SECTION AS FOLLOWS:

A. FINAL TWO MACHINE CUTS NOT MORE THAN .005".

B. SURFACE FINISH 32 MICROINCH OR BETTER.

C. REMOVE ALL CIRCUMFERENTIAL TOOLMARKS WITH EMERY PAPER AND CROCUS CLOTH.

FINISH OF ALL SURFACES BEYOND THE REDUCED SECTION TO BE 125 √ EXCEPT ENDS WHICH MAY BE SAW CUT AND HAVE NO SURFACE FINISH REQUIREMENTS.

TOLERANCES: DECIMAL ± .010, FRACTIONAL ± 1/64, EXCEPT AS NOTED.

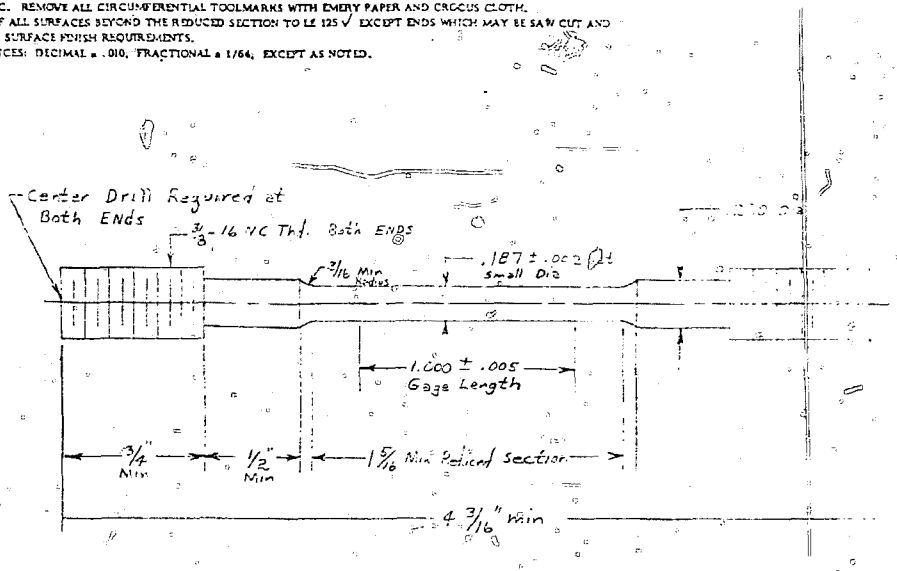


FIGURE 11.

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