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DEVELOPMENT OF SUPERCORRODING ALLOYS FOR USE AS TIMED RELEASES --ETC(U)
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A family of supercorroding magnesium alloys that react spontaneously and vigorously with seawater have been developed at CEL. Supercorroding alloys are so named because of their high corrosion rate in seawater. Investigations of several different alloy formulations show that the alloys can be useful for generation of hydrogen for ocean buoyancy, fuel for thermodynamic engines and fuel cells, production of heat for divers and as self-

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destructing links for retrieval of oceanographic instruments.

Supercorroding alloys with magnesium as the anode material and with several different cathode materials were fabricated and tested to determine mechanical and corrosive characteristics. Alloys with 5 atomic percent iron cathode produce 950 ml of hydrogen per gram of alloy and 13.3 K joules of heat per gram. One gram is over 90% reacted within one minute from immersion. Compacting and sintering produces samples with 9 ksi shear and tensile strengths. Corrosion rates for sintered samples are approximately 9×10^{-3} inches per hour. Alloys with other cathode materials and different levels of cathode content were fabricated and tested. Sufficient data is available on several different formulations of supercorroding alloys to permit preliminary selection for specific applications.

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A family of supercorroding magnesium alloys that react spontaneously and vigorously with seawater have been developed at CEL. Supercorroding alloys are so named because of their high corrosion rate in seawater. Investigations of several different alloy formulations show that the alloys can be useful for generation of hydrogen for ocean buoyancy, fuel for thermodynamic engines and fuel cells, production of heat for divers and as self-destructing links for retrieval of oceanographic instruments.

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INTRODUCTION

The Civil Engineering Laboratory (CEL) has developed a family of supercorroding magnesium alloys that react spontaneously and vigorously in seawater. The alloys predictably self-destruct by corrosion processes and produce usable quantities of heat and hydrogen gas. This research was performed with Independent Exploratory Development funds and conducted during FY-78.

Discovery of the alloys evolved during research aimed at utilizing the accelerated corrosion of magnesium in the form of a short-circuited seawater battery to produce heat for military divers[1]. Although the alloys were originally conceived as an efficient heat and hydrogen gas source, early research[2] indicated other potential applications. The research described herein was conducted to provide further information on the mechanical strength, corrosion properties, and self-destructing predictability of the alloys in compacted powder form for possible use as oceanographic timing and activating devices. Such devices, usually referred to as corrodable links, are useful for recovery of ocean installed instruments, shedding of protective shrouds, delayed activation of mechanical or electrical functions, and scuttling or discarding appendages underwater.

Various cathodic materials in powdered form were mechanically alloyed with magnesium, and evaluated to determine the reaction rate in seawater. Samples of each of the powdered alloys were compacted, sintered and tested to determine their mechanical properties and corrosion characteristics. The goal was to obtain preliminary information on the alloys for use in the design of underwater corroding links.

BACKGROUND

In general, magnesium reacts with seawater according to the formula:

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2 + \text{heat} \qquad (1)$$

The reaction has a theoretical energy density of 14.9 kJ/kg (1885 W-hr/lb)[3] and produces 1.0 liter of hydrogen gas per gram of magnesium (14.8 ft^3/lb) at STP.

By itself, magnesium corrodes slowly in seawater because of low local potential differences within the magnesium. When a suitable cathodic material is brought into close proximity and electrically connected to the magnesium, an electrochemical cell (battery) is formed, and the corrosion reaction proceeds rapidly. The dual-plate cell shown in Figure 1 represents this configuration. When the electrical load is replaced by a short circuit, the reaction proceeds even more rapidly, and the cell efficiently produces heat and hydrogen gas. The rate of reaction has been shown to be a function of (1) electrolyte temperature, pH, salinity, and density, (2) anode-cathode

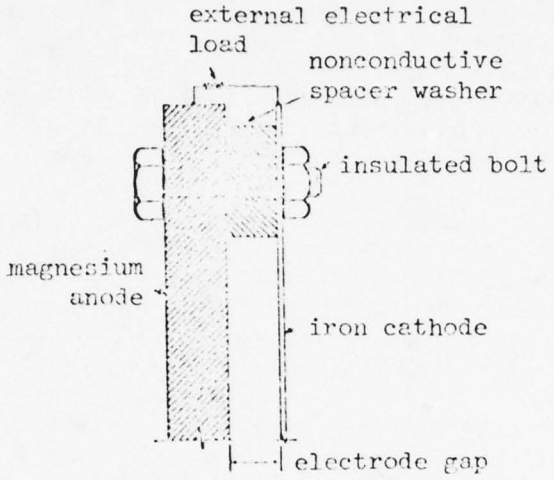

Figure 1. Dual Plate Cell Arrangement. For maximum heat or hydrogen gas production the electrical load is replaced by a short circuit.

plate spacing, and (3) ambient pressure[1,3]. The basic problem with the dual plate cell is that the power decays as magnesium is consumed. That is, as the magnesium plate becomes thinner the electrode gap increases, and subsequently the internal cell resistance increases and power decays.

Supercorroding alloys were conceived as a potential solution to eliminate the dual plate power decay. In the early developmental stage powdered metal mini-cells were fabricated by ball-milling (using lightweight ceramic balls) a mixture of iron and magnesium powders. The milling produced composite powdered particles with iron bonded to the magnesium surface.[3,4,5,6]

Tests showed that rapid corrosion rates were achieved with the mini-cells, but that the reaction efficiency (percentage completion) was low. The accelerated reaction rate was attributed to the close proximity of the anode-cathode pairs and the relatively large cathode surface area. The low efficiency was attributed to poor electrical contact and low mechanical strength of the Mg-Fe particle bond.[3] Hydrogen bubble formation in gaps at the bond surface between the iron and magnesium particles coupled with weak bond strength resulted in many of the bonds breaking before the magnesium particle was completely reacted.

A process called mechanical alloying has been used to develop new materials which overcome the problems that limited the mini-cell's efficiency. The process was developed by the International Nickel Company (INCO) for forming alloys not possible by conventional

techniques.[7] For example, using conventional alloying methods less than 1% iron can be dissolved in magnesium; the INCO process can alloy* virtually any amount of iron that is desired. Samples of powdered alloys have been fabricated with as much as 20% iron content. Tests have shown that magnesium-based alloys from this process react several orders of magnitude faster and more efficiently than the mini-cells.[2] Because of their extremely rapid corrosion rate and high reaction efficiency these materials were named supercorroding alloys.

SUPERCORRODING ALLOY FORMATION

Supercorroding mechanical alloys in powdered form are produced from powdered constituents using a high energy ball mill. The mill containing the powders consists of a vertical cylindrical drum with a series of internal horizontal impellers. The impellers are attached to a shaft which is turned externally by an electric motor. Turning the impellers agitates steel balls inside the drum. Every time steel balls collide, powder particles are trapped between them. The force of impact creates atomically clean surfaces on the trapped particles and welds them together. An inert atmosphere (CO_2) prevents reoxidation of the surfaces. By repeated flattening, fracturing and rewelding supercorroding alloys are formed.

The tendency of powdered particles to cold-weld together predominates during the early stage of the process. As milling continues, the particles get harder and more brittle. Eventually a balance results between welding and particle fracturing. Continued milling refines the particles' characteristic layered structure. An example of this structure is shown in the photomicrograph in Figure 2. The gray areas are iron; the thickness of each layer in the composite particle decreases from repeated impacts. A more complete description of the INCO process for fabricating mechanical alloys is given in reference 7.

*The term alloy or supercorroding alloy used herein denotes a homogeneous mixture of minute galvanic cell particles which have strong bonds between micro-cell constituents and intimate atomic-level electrical contact.

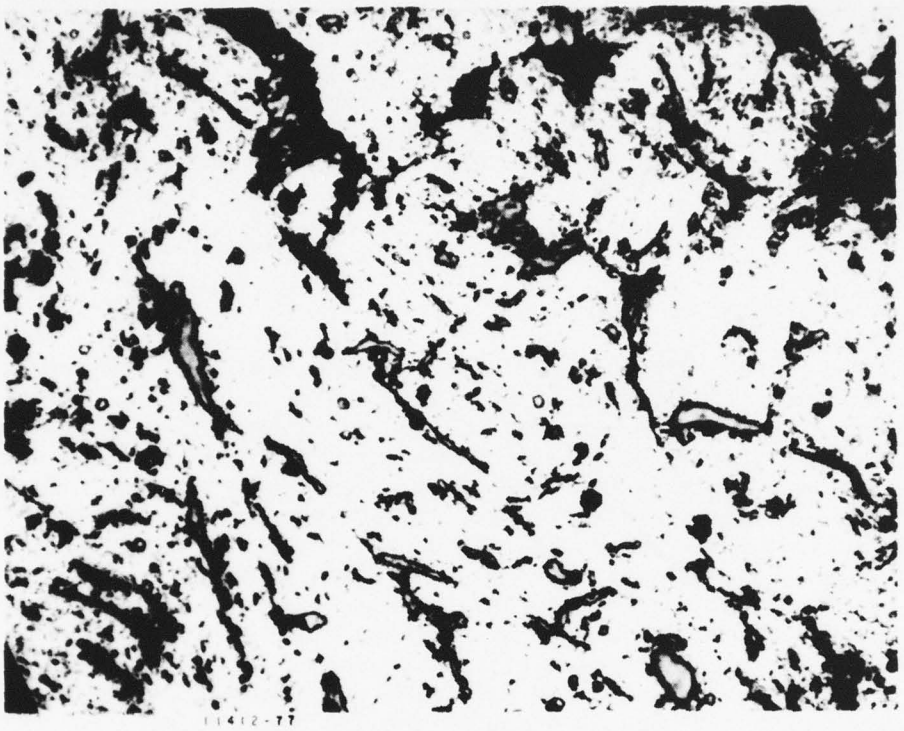

Figure 2. Photo micrograph of mechanically alloyed magnesium-iron particle magnified 500x contains 5 atomic percent Fe. Iron appears as the dark gray areas within the magnesium matrix.

TEST PROGRAM

The compositions of the alloys used to fabricate test samples and for subsequent evaluation were selected from the results of previous research.[2] The objective of this selection process was to obtain a range of reaction rates from hours to minutes. Prior to the manufacture of the final powdered alloys, one specific alloy was produced using several different milling parameters (e.g., milling time and milling energy). These samples of this particular alloy were then tested to determine which set of milling parameters produced the optimum (most rapid) reaction rate and highest reaction efficiency. Because resources did not allow a similar investigation to be conducted for each of the other alloys, this set of milling parameters was used in the manufacture of all the remaining powdered alloys. The list of powdered alloys thus produced is presented in Table 1.

Table 1. Characteristics of Prepared Magnesium Based Supercorroding Alloy Powders.

Cathode Material	Cathode Content (Atomic Percent)	Apparent Density (g/cc)
Fe	.7	.63
Fe	1.6	.63
Fe	4.3	.69
Fe	9.8	.79
Fe	19.0	.90
Ni	4.4	.70
Ti	4.6	.66
Cu	4.3	.71
C	4.3	.59

After fabrication of these powders, samples of the Mg-9.8 Fe* alloy were compacted in the form of barstock (1.07 cm square by 6.5 cm long) and discs (1.27 cm dia by .32 cm thick). The compaction was performed at four different pressures. Several of the 550 M pascal (40 TSI) compacted samples were sintered under various conditions of time and temperature. Testing of these Mg-9.8 Fe samples was used to determine the sintering conditions for optimum reaction rate and efficiency and also the effect of compaction pressure on the reaction. Optimum sintering conditions and 550 M pascal (40 TSI) compaction pressure were then used to prepare barstock and disc samples from the alloys listed in Table 1.

Final testing of the alloys shown in Table 1 was conducted as shown below:

	Reaction Rate	Reaction Efficiency	Time to Failure	Surface Corrode Rate	Mechanical Strength
Powders	x	x			
Barstock			x	x	x
Discs	x	x			

*Mg-9.8 Fe represents a supercorroding alloy with magnesium as the anode material and 9.8 atomic percent iron as the cathode material.

Test Procedure

The corrosion performance of supercorroding alloys was evaluated by collecting the hydrogen produced from the seawater reaction (equation 1) of both powders and disc samples and comparing the results to theoretical gas production. The theoretical volume of hydrogen liberated in the reaction for each gram of magnesium consumed is approximately 1.0 liter at 23.7°C and one atmosphere (15.9 ft^3/lb. mg at 75°F).

The experimental arrangement for powdered alloy and compacted disc tests is shown in Figure 3. Test samples were weighed on an analytical balance and placed in a reaction flask in a constant temperature bath. Fifty milliliters of seawater were transferred from a second flask to the reaction flask. The hydrogen produced by the reaction was then collected in an inverted graduated cylinder. Hydrogen evolved as a function of time was visually observed as water displaced in the graduated cylinder. All data were manually recorded.

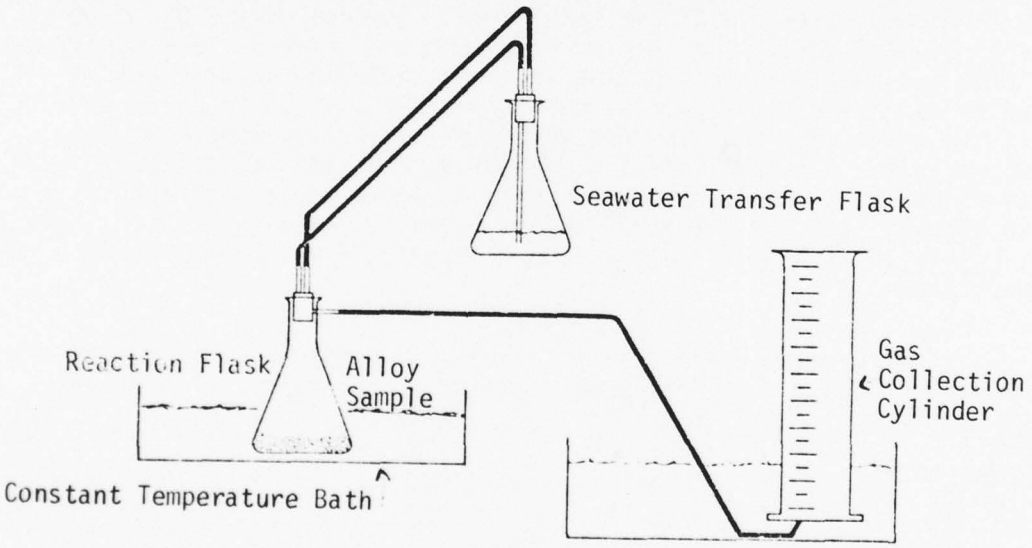

Figure 3. Apparatus for measuring hydrogen produced by powdered and disc samples of supercorroding alloys. The dual hoses between reaction and seawater flasks allow transfer of fluid between flasks.

Barstock samples were tested by INCO to determine transverse rupture (tensile strength) and shear strength. Transverse rupture tests were performed in accordance with ASTM specification B 578-70 except that the specimen thickness was 1.07 cm instead of .64 cm. Shear strength was determined according to ASTM specification B 565-72.

Barstock samples were tested to determine the time to corrosion failure under a fixed tensile load. The samples were drilled at each end to accept nylon fishing line. Except for a .6 cm wide circumferential strip about the center of each bar the surfaces were coated with epoxy cement to preclude seawater contact. A prepared sample is shown in Figure 4. Each sample was placed in a seawater tank with a 5.33 kg tensile load applied to the bar through the fishing line via a weight and a series of pulleys as shown in Figure 5. A trip line, which would activate when the bar corroded through and the ends separated, was attached to an electrical switch on a clock. The clock was manually started when the bar was immersed in seawater and stopped automatically when the ends of the bar separated. In this manner the time to failure was recorded.

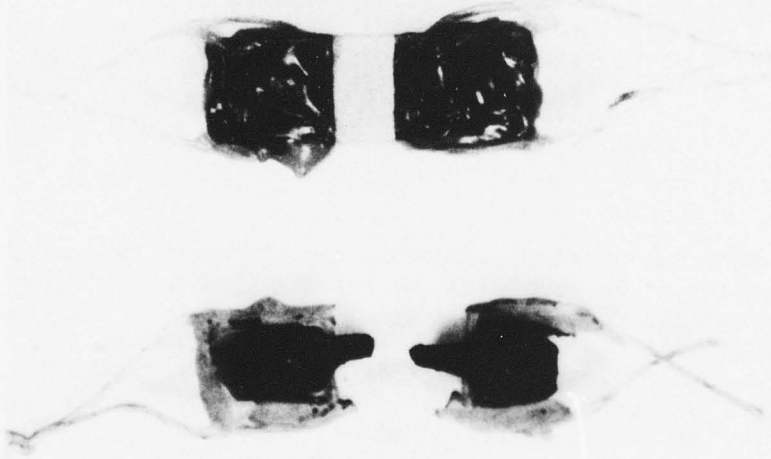

Figure 4. Samples of barstock 3.2 cm long, with a .6 cm square cross-section were prepared as shown above. A weight of 5.33 kg was suspended from the sample which was immersed in seawater. The failed sample is shown above.

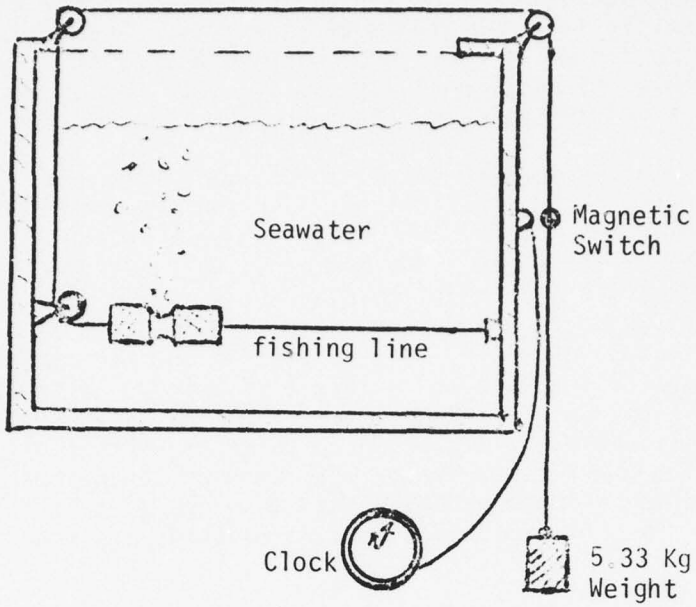

Figure 5. Arrangement for determining time-to-failure of barstock samples prepared as shown in Figure 4. When the sample breaks the weight moves downward and the magnetic switch is opened thus stopping the clock.

Tests were conducted to determine the corrosion rate of a flat surface. Samples of barstock were coated with epoxy cement on all surfaces except for one end. The sample was placed in seawater with the uncoated surface facing up. Measurements of the depth of corrosion were made at regular intervals (out of water) using a micrometer depth gauge. The surface was lightly scraped to remove loose corrosion products prior to taking data.

RESULTS

Powdered Samples

Samples of the Mg-9.8 Fe alloy powder which were fabricated using different milling parameters* were tested to determine reaction rate and reaction efficiency. The test results (Figure 6) clearly show that milling parameters affect reaction characteristics and that optimum performance can be achieved by selecting the appropriate parameters. The milling parameters used in the preparation of sample "A" were selected for manufacture of the remaining alloys.

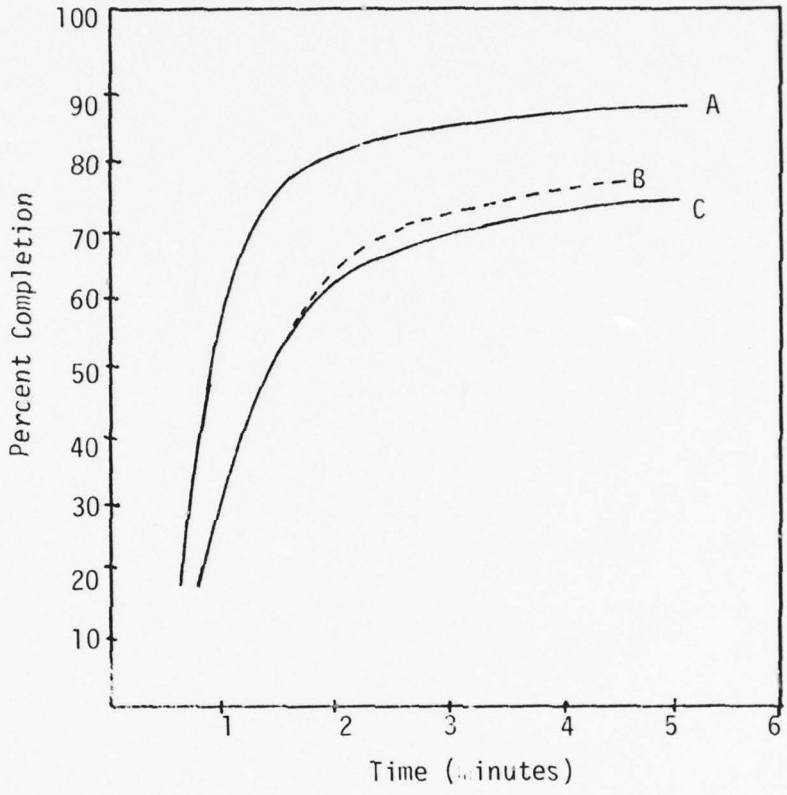

Figure 6. Samples A, B, and C of Mg-9.8 Fe alloy were prepared using different milling parameters such as speed of mill, ball-to-powder ratio and time in mill. Parameters of sample "A" were used for preparation of the remaining alloys.

*Milling parameters included: time of milling; speed of the mill; and ball-to-powder ratio.

Figure 7 presents the results of corrosion tests of magnesium powders with different amounts of iron cathode. Increasing the cathode content results in an increase in the reaction rate.

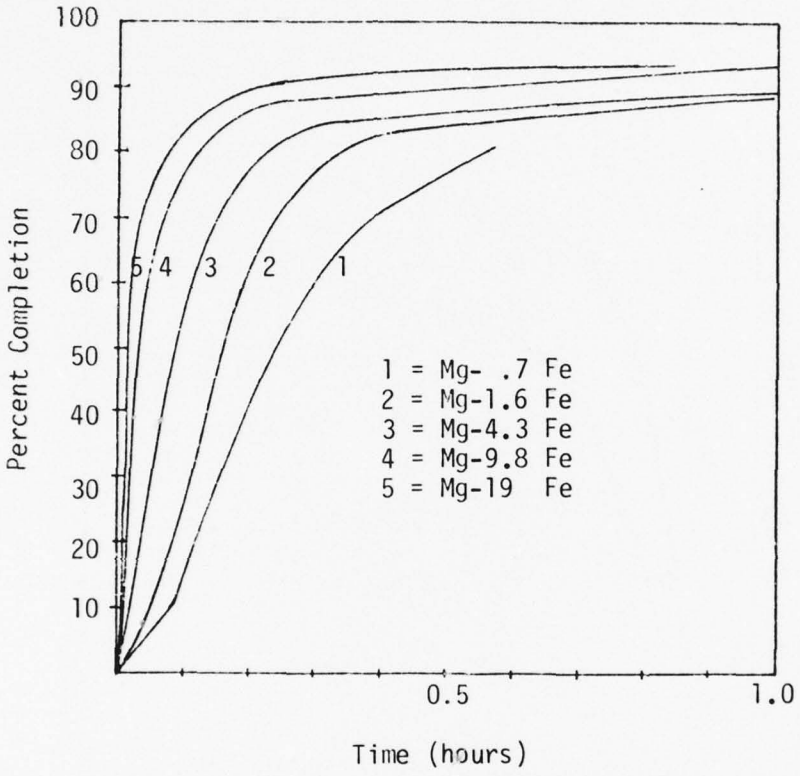

Figure 7. Reaction characteristics for powdered alloys with increasing iron content.

As shown in Figure 8, the reaction rate is a strong function of cathode content up to 10 atomic percent. Increasing the cathode content above 10% only slightly increases the reaction rate. Similar results can be expected for alloys with other cathode materials.

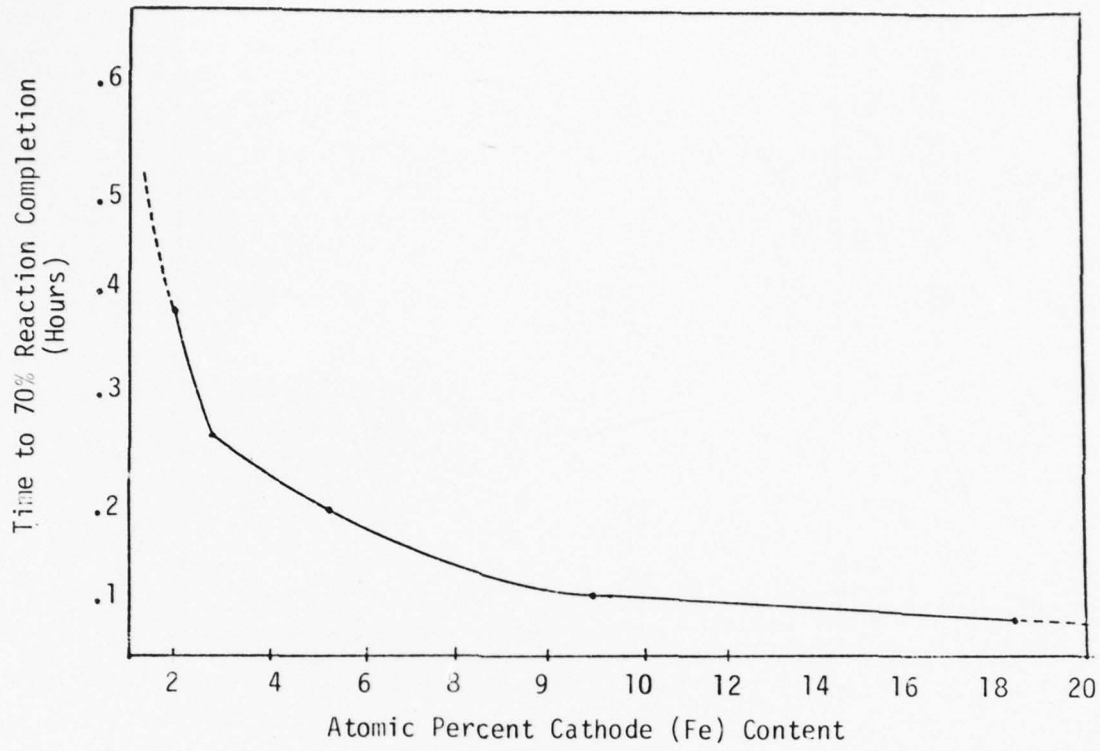

Figure 8. This plot of the time required for alloy powders with different iron content shows the trend of increasing reaction rate for increasing cathode content.

Figure 9 shows the results of tests with the powdered alloys of different cathode material, and approximately the same atomic percent cathode content. The nickel alloy reacted slightly faster than the iron alloy while copper, carbon and titanium (in decreasing order) reacted slower. Note that the iron alloy attained the highest efficiency of the alloys tested. It is expected that the efficiency of the other alloys would be improved by optimization of their milling parameters.

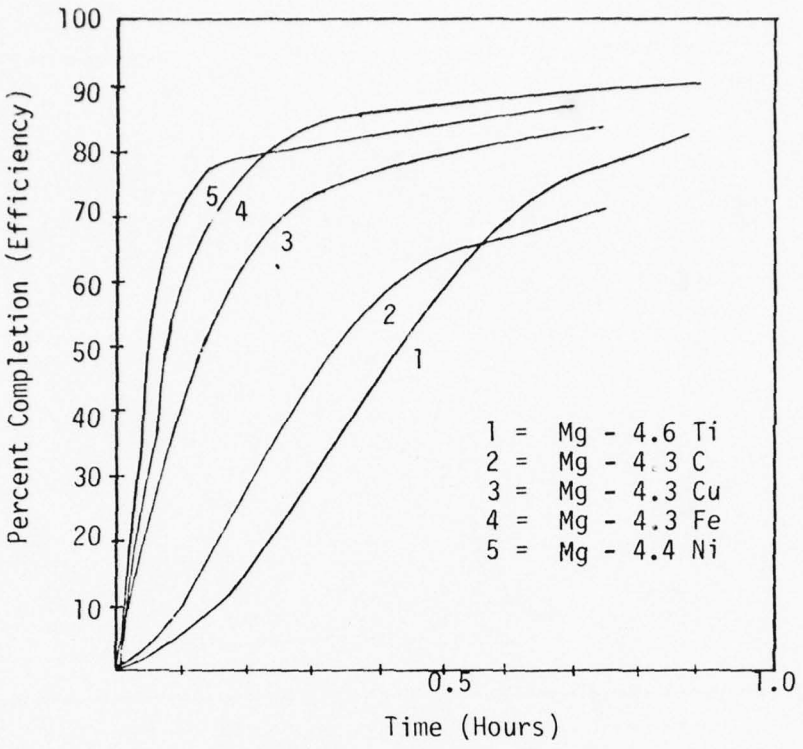

Figure 9. Reaction characteristics for supercorroding alloys with different cathode materials and approximately the same level of atomic percent cathode content. Nickel reacted fastest; iron was most efficient, and carbon reacted slowest.

Sintering and Compaction

Mechanical properties of the Mg-9.8 Fe alloy which was compacted to 550 M pascals and sintered at various conditions are listed in Table 2. Tensile strength (transverse rupture) increases slightly with increasing sinter temperature, while shear strength "peaks" near 700°F. Time of sintering does not seem to appreciably affect the mechanical properties. Since the optimum mechanical strength is a desirable parameter for a mechanical linkage, the sinter conditions of 700°F and one hour duration were selected for preparation of the remaining samples.

Table 2. Properties of Compacted* and Sintered Alloys with 9.8% Fe

Sintering Condition	Sintered Density (g/cc)	Transfer Rupture Strength M pascals (kpsi)	Shear Strength M pascals (kpsi)
600°F/3 h/CO_2	2.11	79.2 (11.5)	71 (10.3)
600°F/1 h/CO_2	2.11	77.9 (11.3)	71 (10.3)
700°F/3 h/CO_2	2.11	88.2 (12.8)	77.2 (11.2)
700°F/1 h/CO_2	2.12	85.4 (12.4)	84.1 (12.2)
800°F/1 h/CO_2	2.10	88.2 (12.8)	69.6 (10.1)

*Compacting pressure - 550 M pascals (40 TSI)

Effects of sintering conditions on corrosion rate of the Mg-9.8 Fe alloy are presented in Figures 10 and 11. Time to failure of the barstock samples for the sinter conditions is presented in Figure 12. The results clearly show that the reaction rate decreases with both increasing time and increasing temperature of sinter.

Mechanical properties of the Mg-9.8 Fe alloy specimens which were compacted at different pressures and sintered at 700°F for one hour are presented in Table 3. As seen in Figure 13, shear strength and tensile strength both increase with compaction pressure.

Table 3. Properties of Compacted and Sintered* Mg-9.8 Fe Powder.

Compacting Pressure M pascals (TSI)	Sintered Density (g/cc)	Transverse Rupture Strength M pascals (kpsi)	Shear Strength M pascals (kpsi)
70 (5)	1.51	2.8 (.4)	11.7 (1.7)
140 (10)	1.83	22.1 (3.2)	32.4 (4.7)
280 (20)	1.99	40 (5.8)	40.0 (7.1)
420 (30)	2.07	62.7 (9.1)	49.6 (7.2)
550 (40)	2.10	71.7 (10.4)	66.8 (9.7)

*Sintered 700°F/1 hr/CO_2

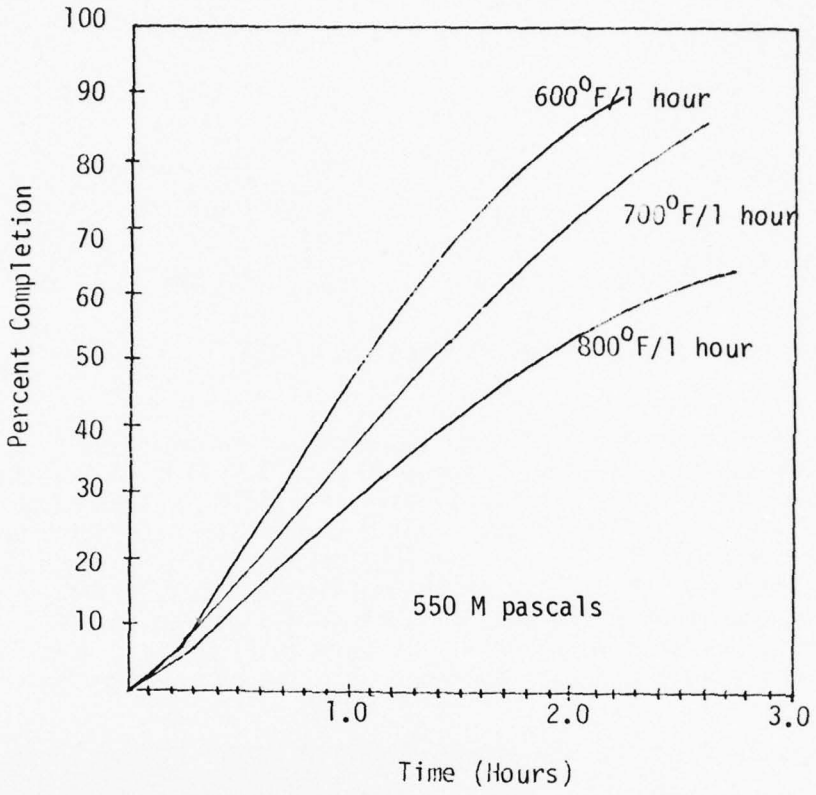

Figure 10. Reaction Characteristics for sample of the Mg-9.8 Fe alloy which were compacted to 550 M pascal (40 TSI) and sintered at the indicated temperatures for one hour in a CO_2 atmosphere. Reaction rate decreases with increasing sinter temperature.

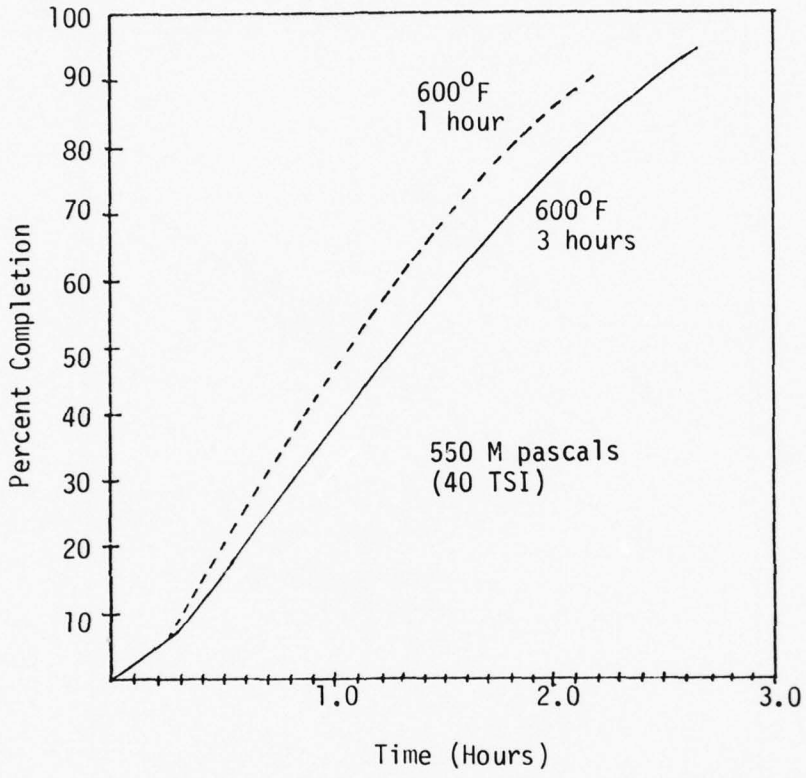

Figure 11. Mg-9.8 Fe alloys were sintered at 600°F for one and three hours. Reaction rate decreases with time of sinter.

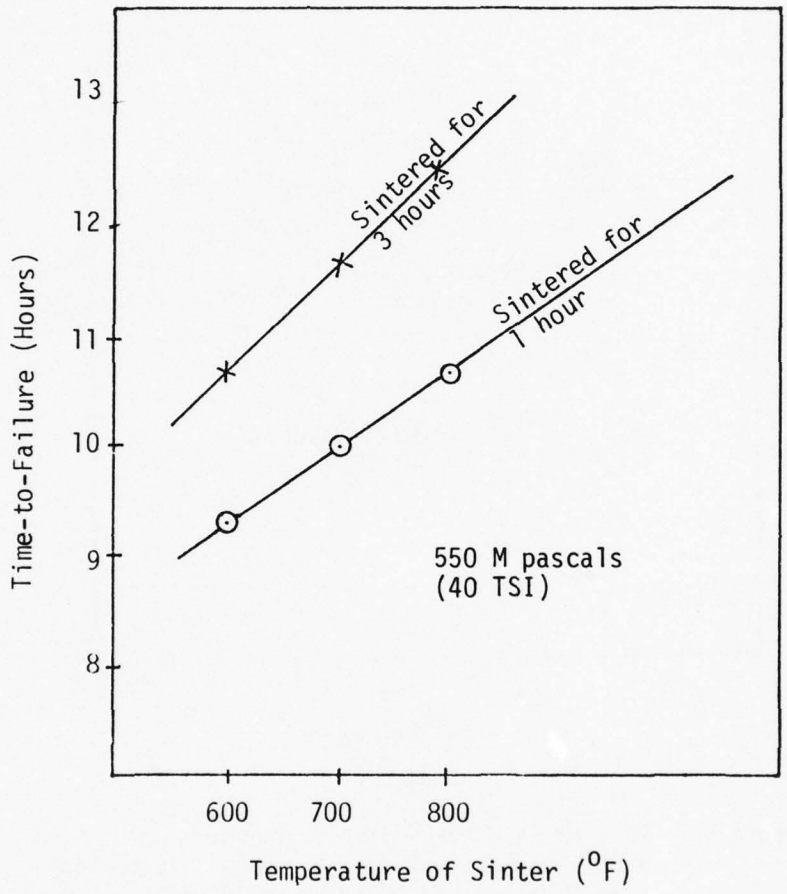

Figure 12. Increasing the time and temperature of sinter effects the time to failure for Mg-9.8 Fe alloys as shown above.

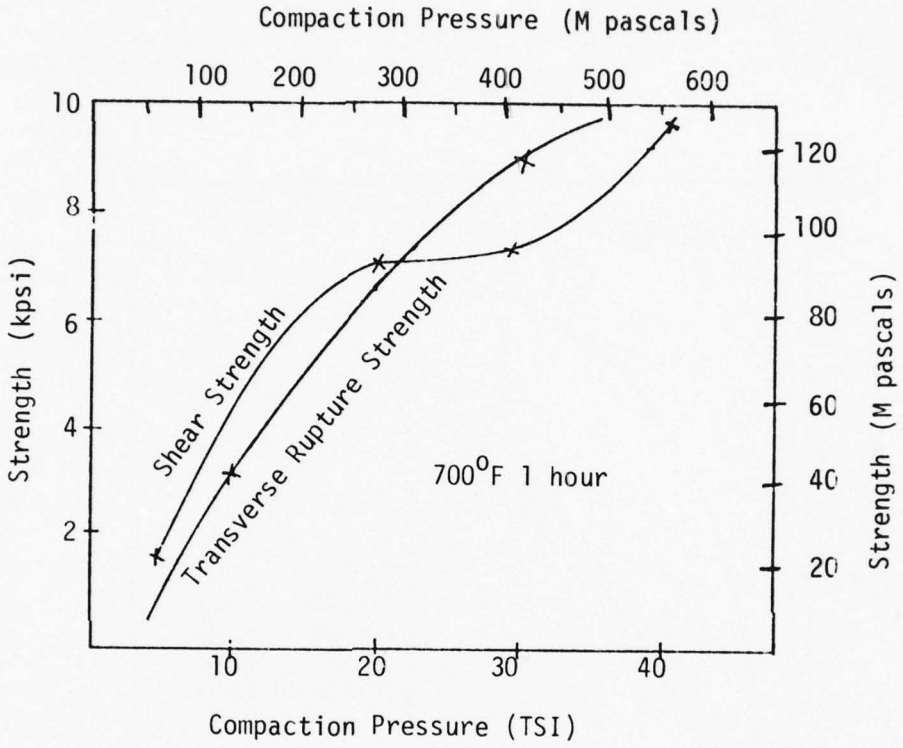

Figure 13. Mechanical strength characteristics for Mg-9.8 Fe alloy samples which were compacted at different pressures and sintered at 700°F for one hour are shown above.

Results of the corrosion tests with discs of each compaction pressure are presented in Figure 14. Powdered sample results are included for reference. The 70 M pascal (5 TSI) sample crumbled immediately on immersion in the seawater and reacted almost as rapidly as the powder sample. Reaction rate decreases with increasing compaction pressure up to approximately 420 M pascals and continues to decrease slightly for increasing compaction pressure between 420 M pascals and 550 M pascals (30-40 TSI). These findings were confirmed by the barstock time to failure tests results as shown in Figure 15. Increasing the compaction pressure beyond 550 M pascals (40 TSI) is not expected to significantly affect either the reaction rate or time to failure.

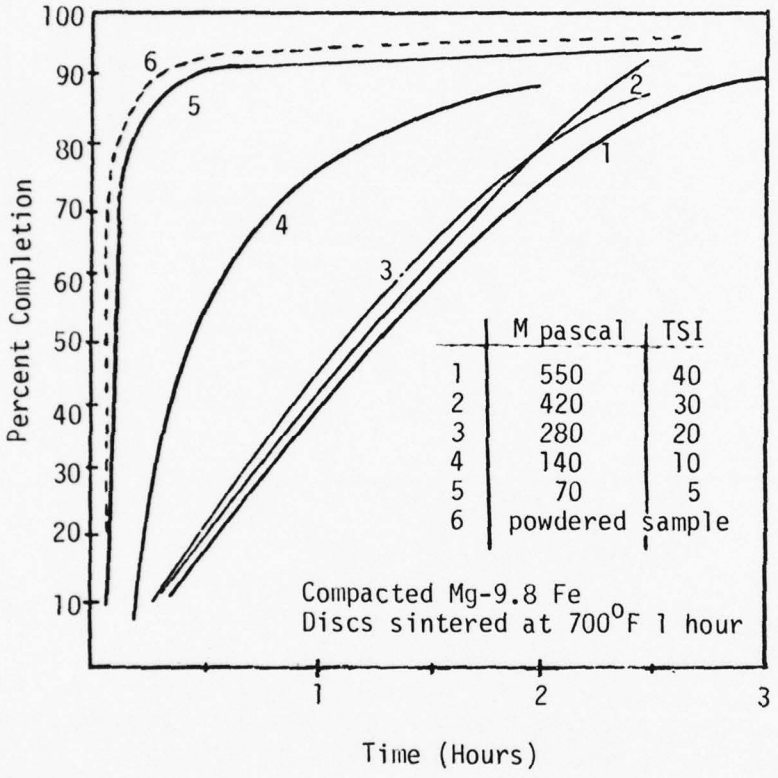

Figure 14. Reaction rate decreases as compaction pressure increases as shown above. The 5 TSI sample reacted almost as rapidly as the powdered sample (dashed line).

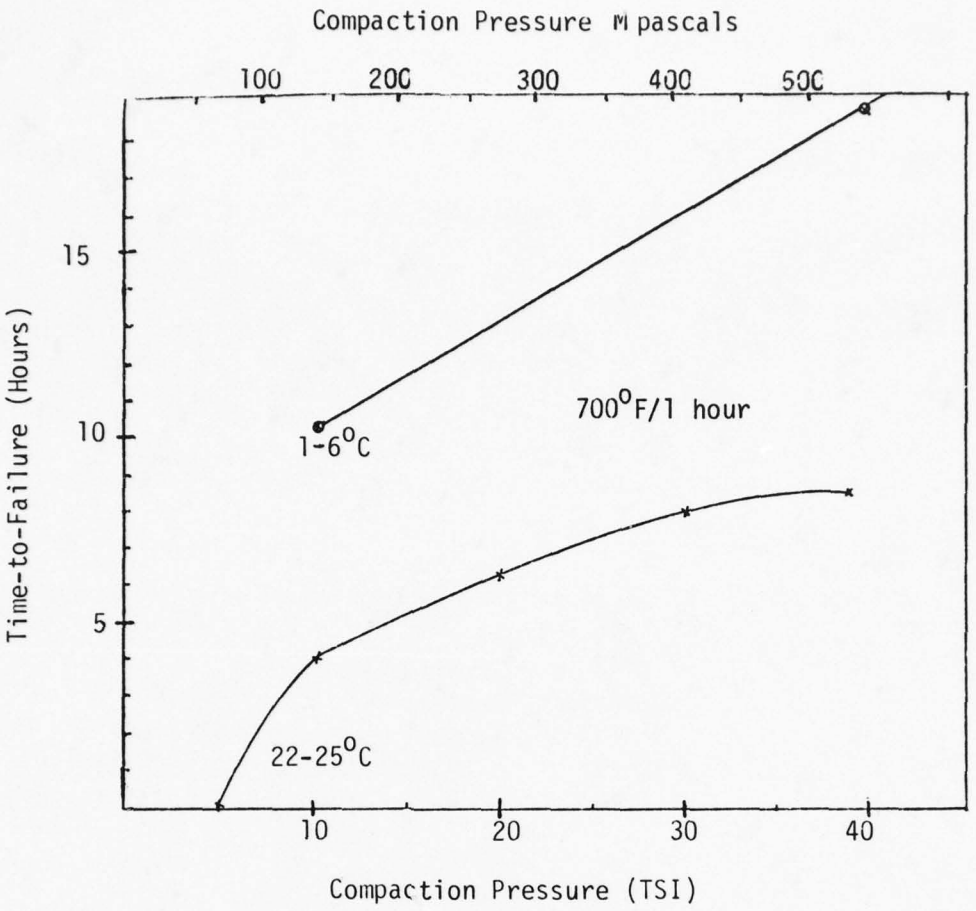

Figure 15. Time to failure for Mg-9.8 Fe barstock samples compacted at different pressures also shown are the results of tests at lower ambient temperature.

Also shown in Figure 15 are the results of two time to failure tests performed at lower ambient temperatures. The tests were conducted by using refrigerated seawater and surrounding the reaction vessel with ice. Starting temperature was approximately 1°C, and at termination the seawater was approximately 6°C. The results show that the time to failure is substantially increased (decreased reaction rate) by lowering the temperature.

Alternate Cathode Compacts

The alloys with different amounts of iron cathode content (iron series) and those with other cathode materials were compacted into disc and barstock form at 550 M pascals (40 TSI). All specimens were sintered at 700°F for one hour in a CO_2 atmosphere. Mechanical properties of these alloys are shown in Table 4. Mechanical strength does not vary uniformly with increasing iron content. The fact that the Mg-9.8 Fe sample is slightly stronger than the others iron series alloys is attributed to optimization of its milling parameters of the prepared samples tested, the Mg-4.6 Ti was strongest with carbon, nickel, iron and copper following in decreasing order of strength.

Table 4. Properties of Compacted* and Sintered* Alloys.

Alloy	PM No.	Sintered Density (g/cc)	Transverse Rupture Strength M pascals	(kpsi)	Shear Strength M pascals	(kpsi)
Mg- .7 Fe	1311	1.79	68.9	(10)	61.3	(8.9)
Mg-1.6 Fe	1308	1.81	64.8	(9.4)	59.3	(8.6)
Mg-4.3 Fe	1309	1.93	61.3	(8.9)	63.4	(9.2)
Mg-9.8 Fe	1306	2.10	71.7	(10.4)	66.8	(9.7)
Mg-19 Fe	1310	2.42	67.5	(9.8)	68.2	(9.9)
Mg-4.3 Cu	1312	1.87	44.1	(6.4)	50.3	(7.3)
Mg-4.4 Ni	1313	1.94	74.1	(10.8)	66.8	(9.7)
Mg-4.3 C	1314	1.78	88.9	(12.9)	65.5	(9.5)
Mg-4.6 Ti	1315	1.89	93.7	(13.6)	80.6	(11.7)

*Compacting Pressure - 550 M pascals (40 TSI)
Sintered 700°F/1 hr/CO_2

Disc corrosion test results for the iron series are presented in Figure 16. Time to failure for the barstock is shown in Figure 17. As expected from the results of the powder tests, the reaction rate increases significantly with higher cathode content.

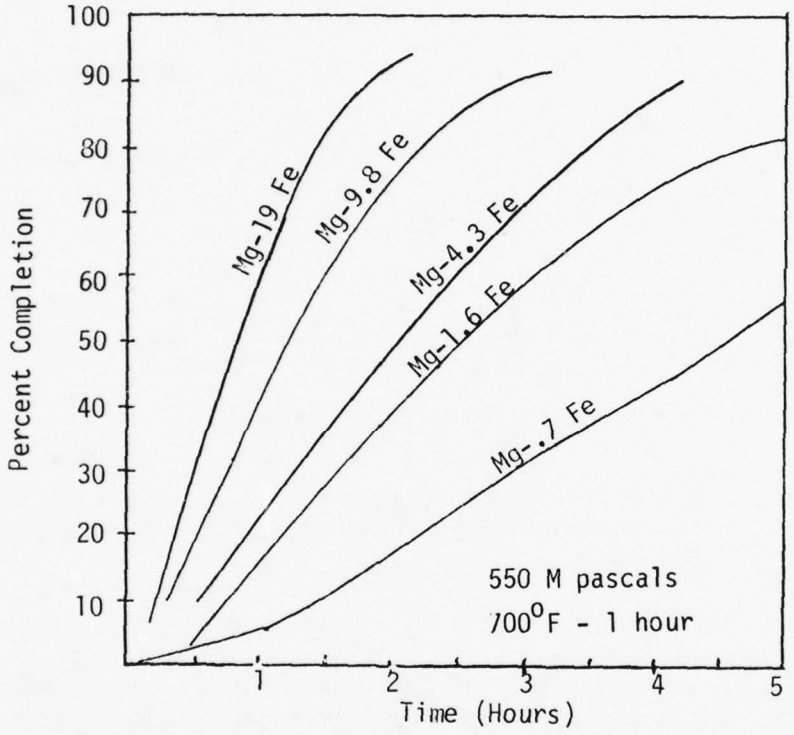

Figure 16. Reaction rate for the iron series alloys discs compacted to 550 M pascals increases with increasing cathode content.

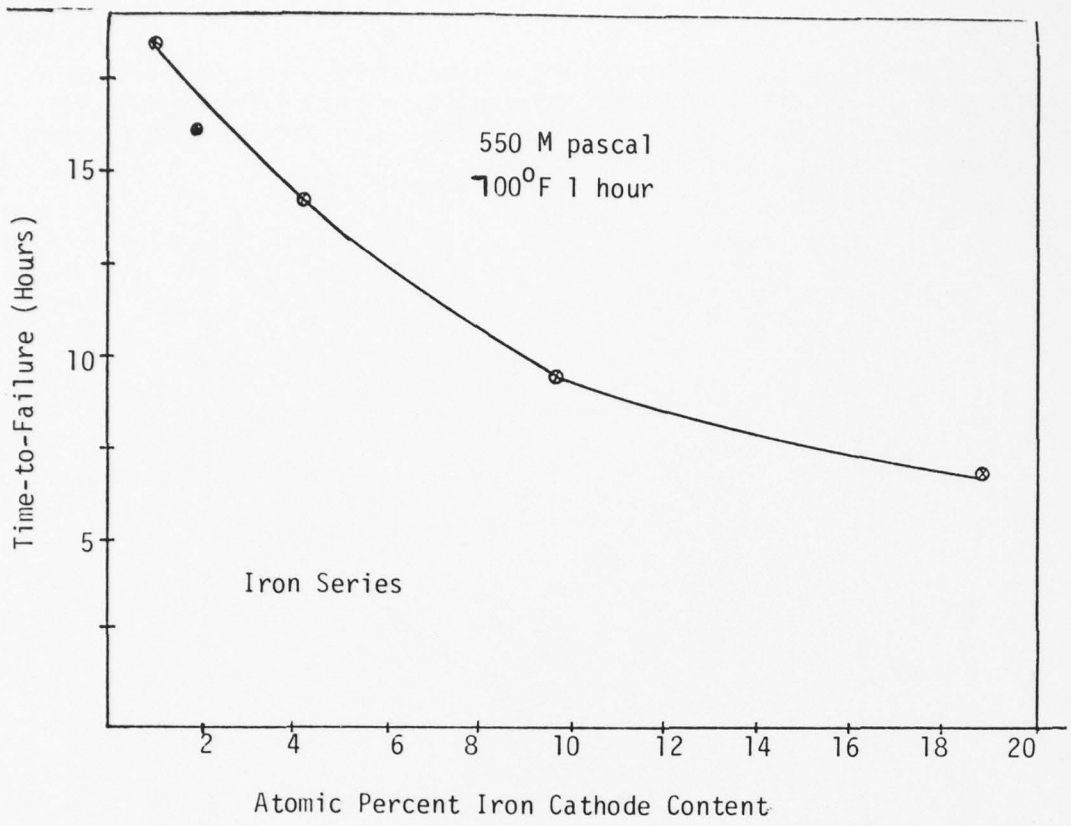

Figure 17. Barstock time-to-failure decreases with increasing cathode content as shown above for the iron series alloys.

The corrosion performance of alloy discs of different cathode materials is shown in Figure 18. Nickel reacted more rapidly with iron a close second. Titanium, copper and carbon in decreasing order reacted slowest. In the barstock time to failure tests (Figure 19) the nickel alloy reacted faster with the titanium alloy second. Iron, copper and carbon alloys reacted slowest.

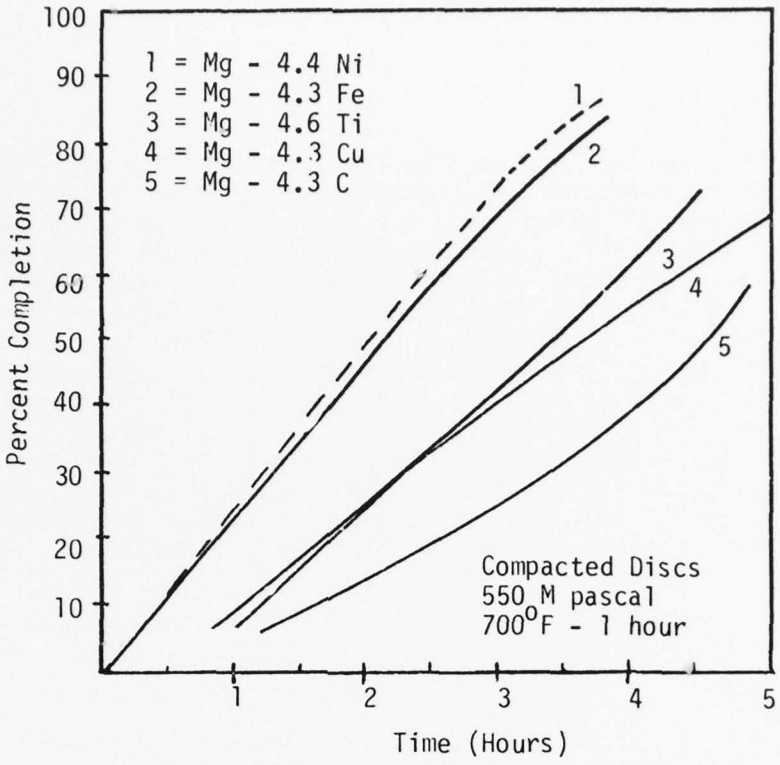

Figure 18. Reaction rate for compacted discs with different cathode materials is shown above.

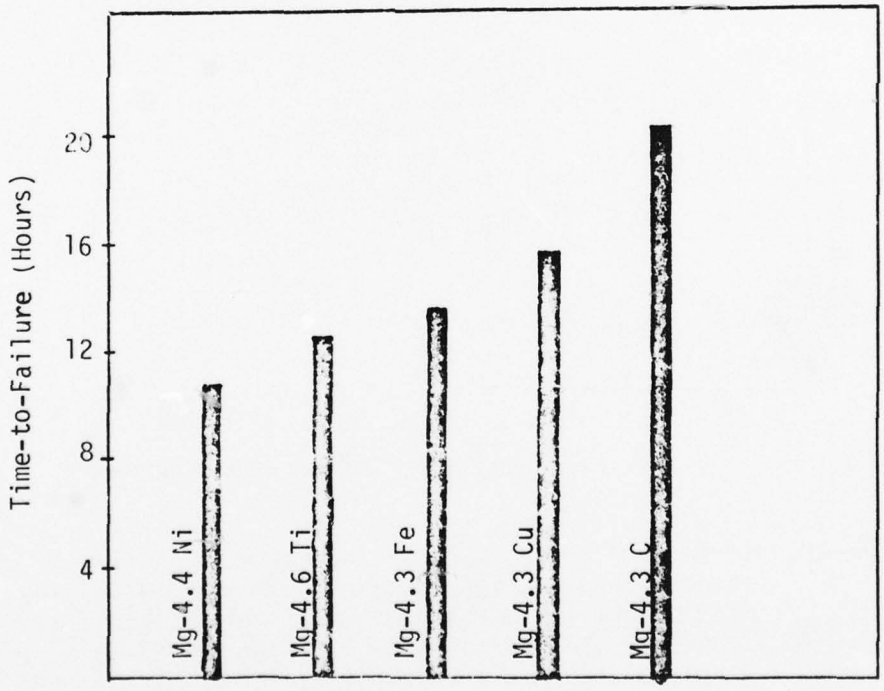

Figure 19. Time-to-failure for barstock samples of alloys with different cathode materials.

Surface Corrosion Rate

Tests were conducted to determine the corrosion rate of a flat surface. The number of tests conducted was limited because of the unavailability of samples. Surface corrosion rates for the iron series alloys are plotted in Figure 20. The corrosion rates for all alloys tested are presented in Figure 21. Note that two different corrosion rates are given. It was found that the alloys corroded slower during the first six hours of immersion (dashed line of Figures 20 and 21) than during the remaining test hours (20 hours). The difference was attributed to changing conditions on the test specimen wetted surface. On immersion, the surface was smooth. As corrosion proceeded the surface became pitted and consequently the exposed surface area increased. Eventually (3 to 6 hours after immersion) the exposed surface area became relatively constant and corrosion proceeded at a steady rate. The solid lines in Figures 20 and 21 represent the steady state corrosion rate after six hours of immersion.

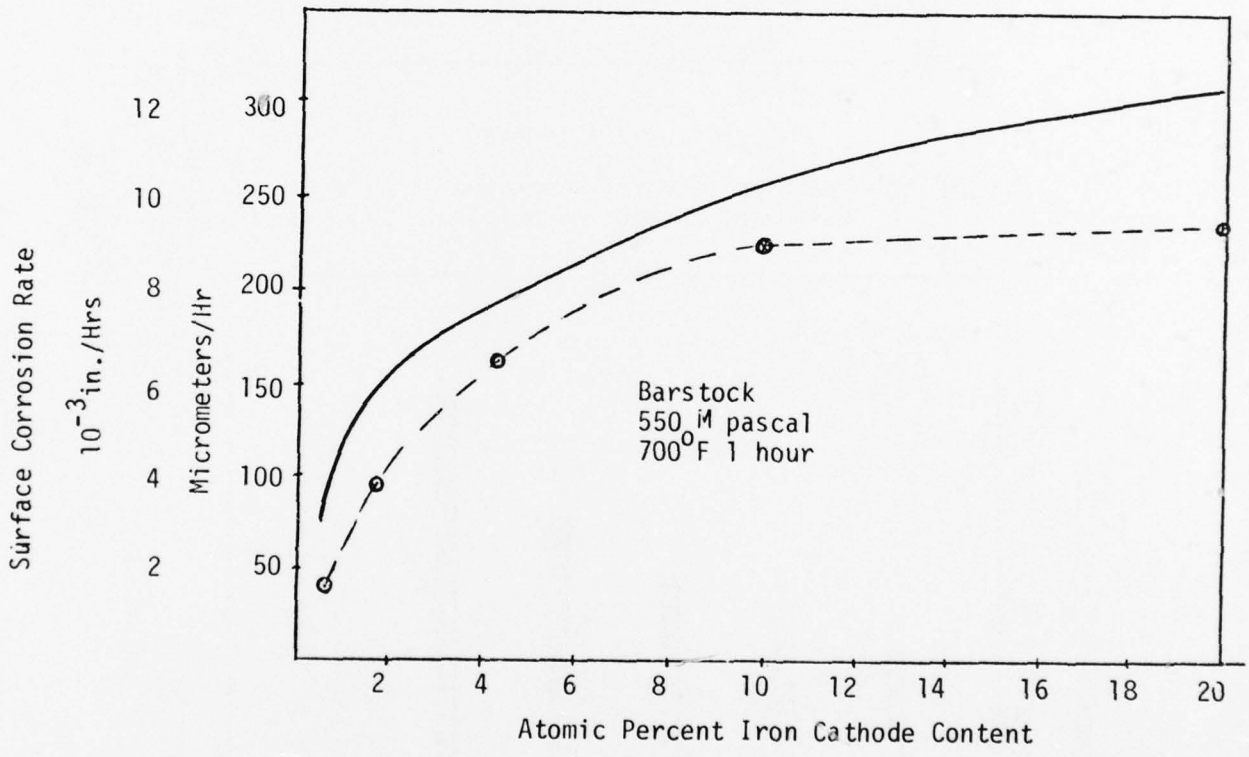

Figure 20. Surface corrosion rate for alloys with different percent iron cathode content. Corrosion decreases with decreasing cathode content. The dashed line indicates the corrosion rate during the first 6 hours and the solid line the corrosion rate from 6 to 20 hours.

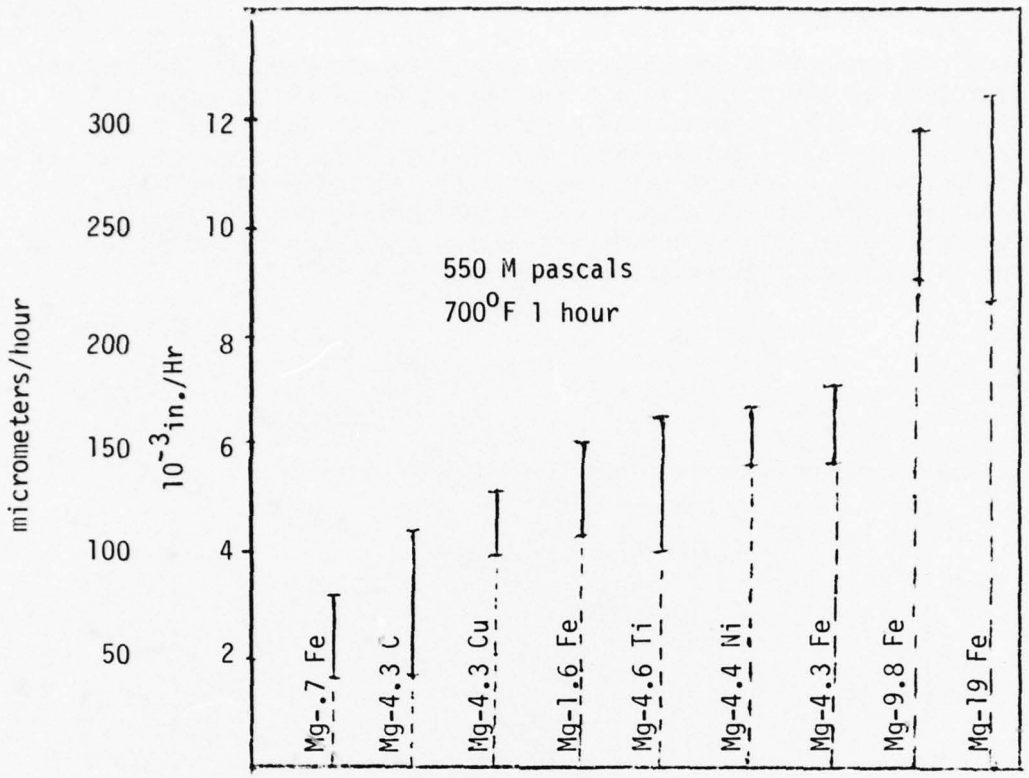

Figure 21. Summary of surface corrosion ratio for all samples tested. The dashed line indicates corrosion rate during the first 6 hours and solid line the corrosion from 6 to 20 hours.

As expected, from the results of previous tests, the surface corrosion rate increased with increased cathode content and the general order of ranking (Fe, Ni, Ti, Cu and C) remained unchanged from the results of disc tests.

Discussion

Results of tests with the Mg-9.8 Fe powder as shown in Figure 6 demonstrated that alloy corrosion performance was affected by manufacturing parameters. The optimum manufacturing parameters for each alloy (in terms of reaction efficiency and strength) are probably unique for that alloy.

An investigation of the milling parameters for each alloy tested would result in a faster reaction rate and higher reaction efficiency. The effect of milling parameters on mechanical strength, time to failure for barstock and surface corrosion rate is not known at this time.

Combined compacting and sintering significantly reduces the reaction rate over that of the powder form. The magnitude of this change is shown in Figure 22 by a comparison of the results of power and disc samples (550 M pascals) for the Mg-4.3 Fe alloy. Reducing the compaction pressure below 550 M pascals will result in increased reaction rate and decreased mechanical strength. For applications where strength is important, compacting to 550 M pascals and sintering to 700°F for one hour in a CO_2 atmosphere are recommended.

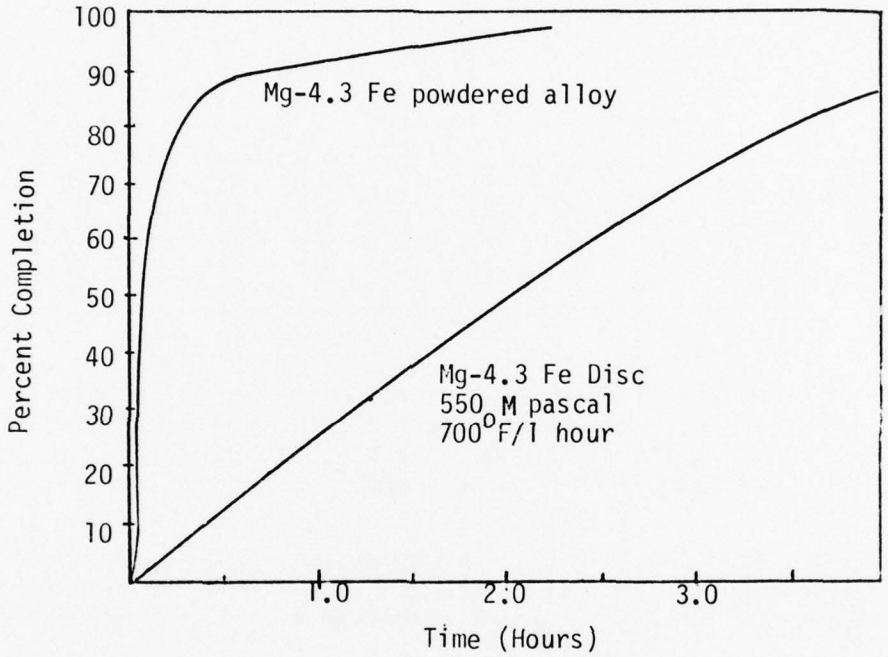

Figure 22. Shown is a comparison of the reaction rate for the disc and powered samples for the Mg-4.3 Fe alloy. Compacting greatly reduces the reaction rate.

In addition to milling, compacting, and sintering, alloy corrosion performance is a function of the amount and type of cathode material present. Figure 23 summarizes the results of powder, disc and barstock tests for the iron series alloys. The reaction rate increases with cathode content up to 20 atomic percent. Increasing the cathode content over 20 percent will not result in a significant change in the reaction rate. Similar results are expected for other cathode materials.

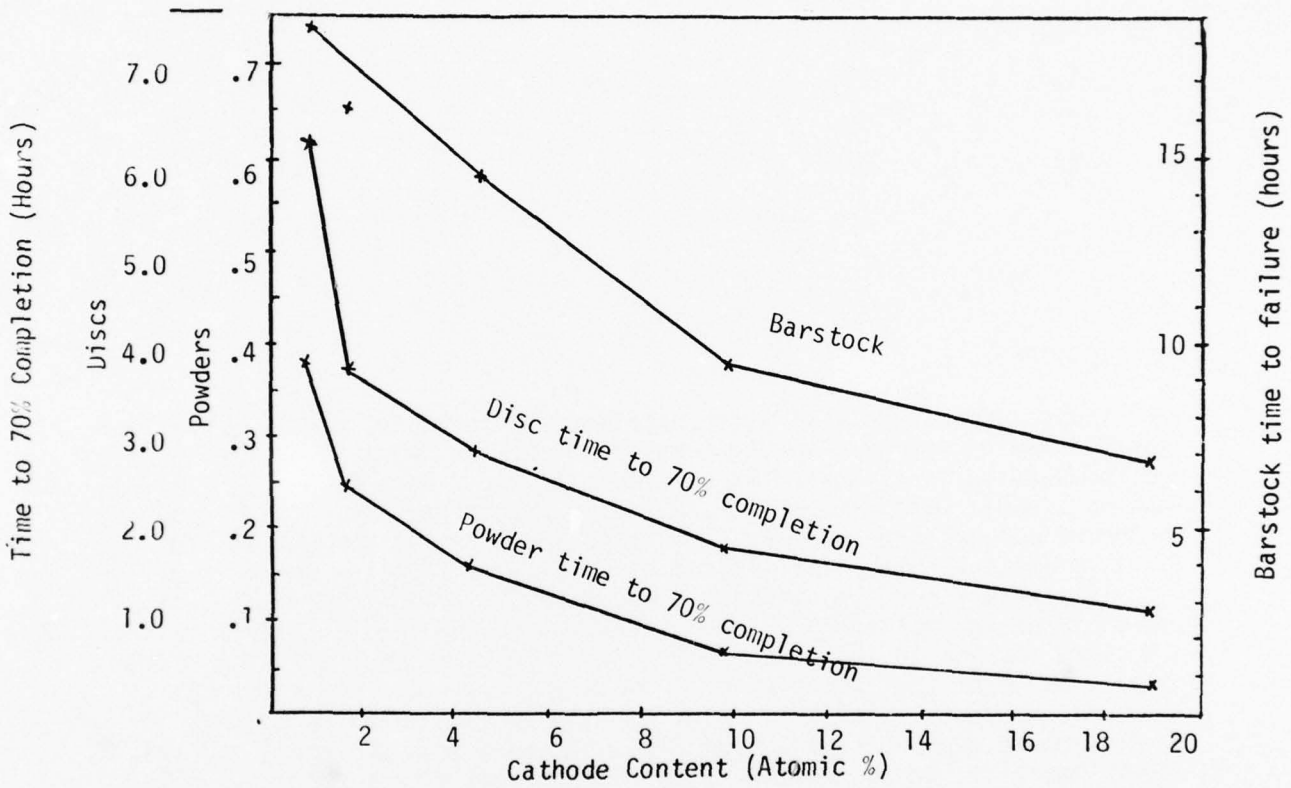

Figure 23. A summary of the results of powder, disc and barstock samples for the iron series shows the effect of cathode content on reaction rate.

Reaction rate, time to failure, surface corrosion rate, and mechanical strength of the alloys tested also depend on the cathode type. Ranking for the different cathode materials tested is summarized in Table 5.

Magnesium with titanium as the cathode formed the strongest alloy tested while magnesium with nickel reacted fastest.

Table 5. Order of Ranking for Materials Listed.

Fast	Powder	Disc	Barstock Failure	Surface Corrosion
	Ni	Ni	Ni	Fe
	Fe	Fe	Ti	Ni
	Cu	Ti	Fe	Ti
↓	C	Cu	Cu	Cu
Slow	Ti	C	C	C

APPLICATIONS

Supercorroding alloys were conceived as sources of heat and hydrogen gas for use in remote areas such as in the ocean. Heat and hydrogen gas production is discussed in reference 2. As a heat source, the alloys can be used to warm divers or melt ice in arctic regions. The hydrogen produced can be used to power fuel cells and internal combustion engines, or to provide buoyancy for lifting heavy objects from the ocean floor.

The research discussed herein was selected to generate information which is useful for applying the technology to the design of self-destructing linkages for use in the ocean. The link could be in the form of a round pin which holds the object to be released to an anchor or instrument package. Another useful form for a corrodable link would be that of a flat round disc one surface of which is exposed to the ambient seawater. Upon immersion the surface would corrode and the disc eventually fail. The failure could be used to facilitate flooding and scuttling or to activate other mechanical and electrical functions.

Desirable failure time for corrodable linkage devices varies depending on the application. For example, it may be desired to retrieve a sampling device within one to eight hours of deployment. In another application, it may be desirable to scuttle a surface float such as a sonobuoy after eight to ten days of operation.

The present method of design for corrodable linkages is to form galvanic couples of dissimilar metals, the anode of which serves as the destructing link. This type of linkage has been generally unreliable because of the need for a reliable low resistance connection between the anode and cathode materials. Even a slight degradation of this connection can result in a significant change of the activation or release time.

Supercorroding alloys offer a solution to the difficulties experienced with presently used corrodable links. With supercorroding alloys the anode (magnesium) and cathode (iron, nickel, etc.) are combined to form a material which self-destructs on immersion in seawater. The destruction time depends on several factors such as cross sectional area of the link, cathode material, percent of cathode material present and surrounding temperature. The data presented herein provides a baseline by which a preliminary assessment of alloy performance and applicability for use in a particular application can be determined. Further refinement of the technology can be tailored once a specific application is defined.

SUMMARY AND CONCLUSIONS

Alloys of magnesium and various cathodic materials were fabricated by the International Nickel Company (INCO) and tested by the Civil Engineering Laboratory (CEL) to determine their corrosion properties. In both powdered and solid form, the alloys were found to have a high reaction efficiency. In powdered form, the alloys corrode rapidly and the rate of corrosion depends on both the cathode type and cathode content. Magnesium with either a nickel or iron cathode corrode most rapidly. Compacting and sintering the alloys produces solid forms that have significant shear and tensile properties which can be useful as self-destructing linkages and timing mechanisms for use in the ocean. The activation or failure time of the linkage can be tailored by selection of the cathode content and cross-section dimensions. In this manner, it is expected that activation times from minutes to days can be reliably achieved.

The preliminary data provided in this report can be used to determine the applicability of supercorroding alloys in a particular application.

Final selection of the alloy cathode and level of cathode present depends upon the end use. Prior to manufacturing a particular alloy a study of the effect of milling parameters on corrosion performance should be performed. This study will insure optimum corrosion performance, mechanical strength and uniformity of the final product.

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