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Luxfer MEL Technologies' SoluMag® Magnesium Alloy

Luxfer MEL Technologies, the technology leader in high performance magnesium alloys, has developed a high strength, high corrosion rate alloy named SoluMag for downhole hydraulic fracturing tool applications. Our datasheet for SoluMag covers the standard information about this material. This Technical Bulletin is in addition to the datasheet for SoluMag, to more fully describe the material's performance in a variety of situations and tests. This Technical Bulletin will be updated on an as-needed basis.

Luxfer MEL Technologies (LMT) is a magnesium alloy producer based in the UK, that works to find the best alloy technology for given applications. Whether it is cast, extruded, rolled or powder metal technology, LMT offers a wide and deep range of magnesium alloy solutions that fit the application. With 4 different SoluMag versions (SoluMag 1100, SoluMag High Ductility, SoluMag High Strength and SoluMag Freshwater), we can help the engineer and designer to apply the right material for the application.

Our extensive knowledge in magnesium alloys comes from 80+ years of technological innovation and discoveries. This technical bulletin covers the SoluMag 1100 product but most of the information applies to the other three alloys as well. For clarification with the other SoluMag alloy properties, contact us for an in-depth discussion on the material.

SoluMag Corrosion Rate

Corrosion rate in chloride containing solutions

SoluMag magnesium alloy is designed to reliably corrode in chloride solutions. Chart 1 shows the corrosion rate at chloride levels from pure water to 3% and above. In above 1% solutions, the corrosion rate is nominally the same at 3% and higher solutions. The corrosion rate is active at 0.5% and at 0.25%, it is 200 mg/sqcm/ day rate. These tests were done at 100, 150 and 200 F. Results for corrosion rate tests in sodium, calcium and other salts solutions are available.

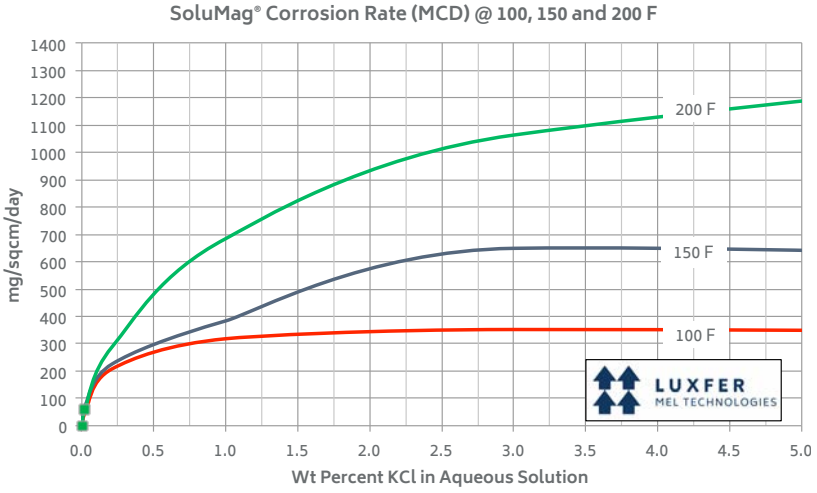


Chart 1. Corrosion rate vs salinity at different temperatures for SoluMag 1100.

Corrosion reaction explanation

SoluMag magnesium alloy displays a high corrosion rate when exposed to saline solutions above 1% (10,000 ppm). This reaction is unique in that the chloride acts like a catalyst as it is not consumed by the magnesium in the process. The specifics of the reaction are:

$$Mg + 2H_2O + Cl^- \text{ --> } Mg(OH)_2 + H_2 + Cl^- + \text{heat}$$

Note the SoluMag needs water to react. Magnesium hydroxide, $Mg(OH)_2$ has limited solubility in water, so a flow of produced fluid is required to keep the reaction product from forming a sludge around the SoluMag part and stopping the reaction. In a confined space downhole, the SoluMag and magnesium hydroxide will consume all of the available water and dry out if no fresh fluid can get to the material. In this case, the reaction will stop or slow down significantly.

Corrosion product characterization

The corrosion of SoluMag magnesium alloy creates magnesium hydroxide, a fine solid particulate material that is only slightly soluble in water. Magnesium hydroxide, also called milk of magnesia, is a common component of antacids and laxatives for human consumption and is very benign. These solid magnesium hydroxide particles are very fine, typically less than 150 mesh. This is much finer than frac sand proppant and it will consequently flow out of the well given some fluid movement.

Comparison with other magnesium alloys

In testing other standard magnesium alloys for corrosion rate in chloride containing solutions, we have found that SoluMag has a corrosion rate that is between 100 and 10,000 times higher than typically available commercial alloys.

Corrosion rate at various temperatures

The corrosion rate of SoluMag magnesium alloy varies depending on the temperature of the surrounding fluid. Tests from 40 F to 200 F have been completed to determine the corrosion rate under atmospheric pressure. Corrosion rate tests were completed in 3% KCl solutions and the results are shown in Chart 2. The relationship between temperature, pressure and corrosion rate is complex. We have tested SoluMag up to 15,000 psi and will share the corrosion rate data under a non-disclosure agreement.

Corrosion rate in high pH (basic) solutions

The corrosion rate of SoluMag magnesium alloy varies depending on the pH of the surrounding fluid. At low pH levels, the corrosion rate increases considerably. At pH levels between 5 and 10, we would expect normal or typical corrosion rates to be present. When the corrosion rate is very high, above 10, due to the presence of caustic or other high pH materials, it is unclear what corrosion rate should be expected. Testing under these high pH conditions has not been done.

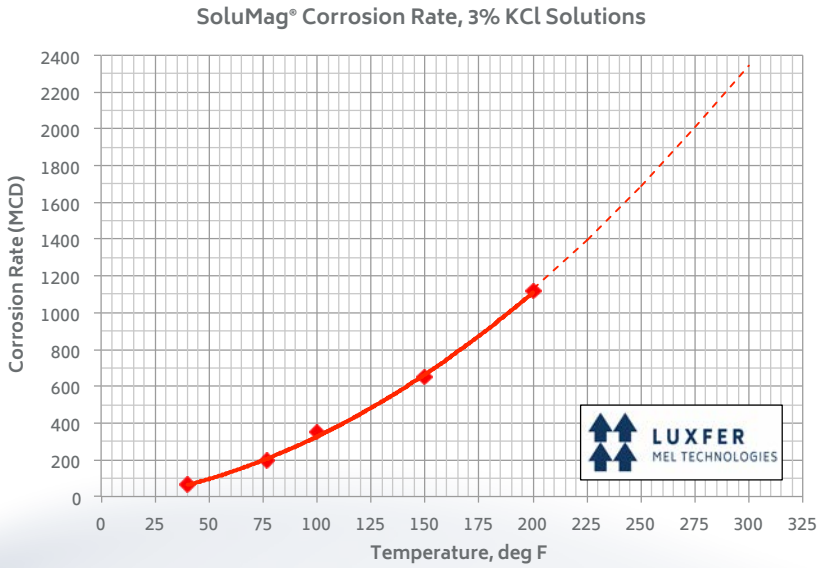


Chart 2. Corrosion rate vs temperature for SoluMag 1100.

Corrosion rate in low pH (acid) solutions

All magnesium alloys, including SoluMag, react vigorously in aqueous acid solutions. Hydrochloric acid (HCl), a typical acid in the oil field, is often used downhole to clean and clear obstructions inside the casing and out and is normally used in liquid concentrations from 1 to 28% in water solutions. The higher the concentration of HCl in water, the more reactive it will be with SoluMag or any magnesium alloy. In the reaction between HCl and the magnesium metal in SoluMag, the acid is neutralized and the pH of the solution is increased. The reaction rate is very high during the initial phase but as the acid is neutralized, SoluMag will continue to react with the chloride ions in the aqueous solution at the normal level. The amount of acid around the SoluMag item is important as to whether all the magnesium is reacted at the high corrosion rate period. SoluMag corrosion rates of 100 times the normal salt solution corrosion rate have been measured in the dilute acid solutions at room temperature.

The use of HCl acid in the wellbore with SoluMag is possible but unless the metal is well protected, will result in a very fast dissolution of the SoluMag component. Inhibited HCl acid has the same corrosion rate as uninhibited HCl on SoluMag.

Corrosion rate in other chloride and bromide solutions

SoluMag has been tested extensively in potassium salt (KCl) solutions and in other chloride-containing salt waters as well as some aqueous bromine solutions. The results are that SoluMag, in each different solution, will have its own corrosion rate characteristics. Some salts accelerate the corrosion rate, some depress the rate. Luxfer MEL Technologies can test most of the salt combinations and can help you predict the corrosion rate performance. Contact us for a review of this work and how we can help in this testing.

Corrosion rate in other terms

Luxfer MEL Technologies has stated the corrosion rate of SoluMag as 1100 MCD under particular temperature and salinity conditions. MCD is short for milligrams per square centimeter per day, the amount of material that can be corroded away from an amount of surface area per day. To convert MCD to MCH, divide the MCD value by 24. To convert the MCD value to inches per day (IPD) from a planar surface, divide MCD by 4562.5. An 1100 MCD material is a 0.24 IPD corrosion rate from a plain, flat surface.

MCD to IPD conversion

To convert MCD (milligrams/sqcm/day) values to IPD (inches per day of ball diameter reduction), please consult Chart 3 below. At 300 MCD, a SoluMag ball diameter will reduce by 0.13 inches per day. Corrosion on a SoluMag ball is general, evenly distributed across the entire surface. The corroded surface is very rough and the calculations below are based on the weight reduction, converted back to a hypothetical round ball.

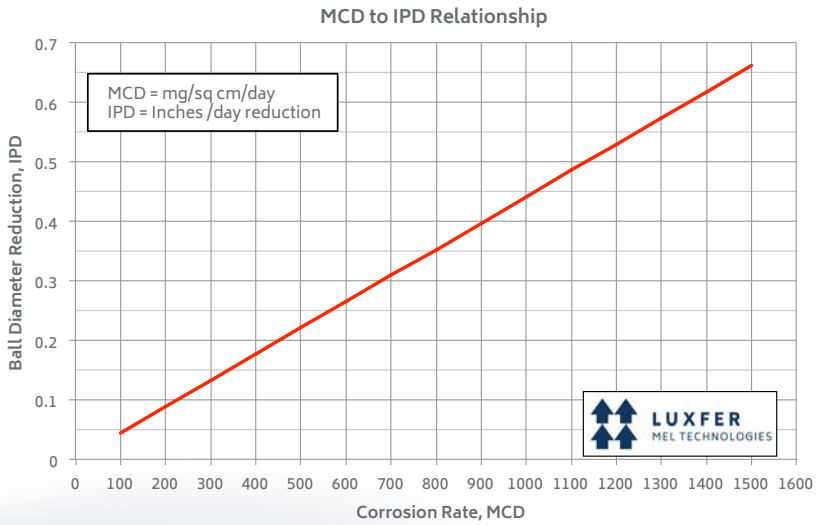


Chart 3. Corrosion rate in relation to inches per day reduction of a ball diameter.

Corrosion rate test

Luxfer MEL Technologies has studied the SoluMag corrosion rate reaction and the variables that are involved in determining the corrosion rate of materials. We can supply the details of our corrosion rate test for your review and understanding of this test. The details of the corrosion rate test will affect the results. Contact us today for a copy of this test description to ensure you are measuring the material accurately.

Material Properties

SoluMag Magnesium Alloy Forms Available

As a wrought magnesium alloy, SoluMag is available as an extruded product in various forms. SoluMag can be extruded as small as wire to as large as 6 inch diameter in round rod form. Luxfer MEL Technologies produces tubes, square and rectangular forms as well as complex hollow shapes to meet your design requirements and minimize the losses from machining.

SoluMag Magnesium Alloy Machining Chips

Machining SoluMag or any magnesium alloy produces chips that are a fire hazard. It is Luxfer MEL Technologies' recommendation that magnesium alloys are best machined dry, without a coolant. Wet magnesium chips are a significant fire hazard that risks a runaway exothermic reaction. Contact us for information on magnesium chip safety practices and machining information before any machining begins. We want you to work safely with the material and know the risks before starting any work.

Mechanical strength properties

SoluMag extruded materials have been tested in tensile and compression orientations both in longitudinal and transverse directions (longitudinal direction is in the direction of the extrusion axis, transverse is perpendicular to the extrusion direction). Percent elongation data for longitudinal and transverse directions indicate excellent ductility in this extruded product. This material is not brittle at low atmospheric temperatures nor does it soften until the temperature gets above 400 F. In terms of Charpy v-notch impact strength, SoluMag exhibits typical values of 20ksi [138 MPa], like 6000 series aluminum alloys.

High temperature mechanical strength

SoluMag magnesium alloy has excellent high temperature strength characteristics. Chart 4 shows how the material tensile strength is maintained at higher temperatures. Note that these are tensile strengths measured at the temperature indicated. Once the material is returned to normal temperatures, the properties return to their original values.

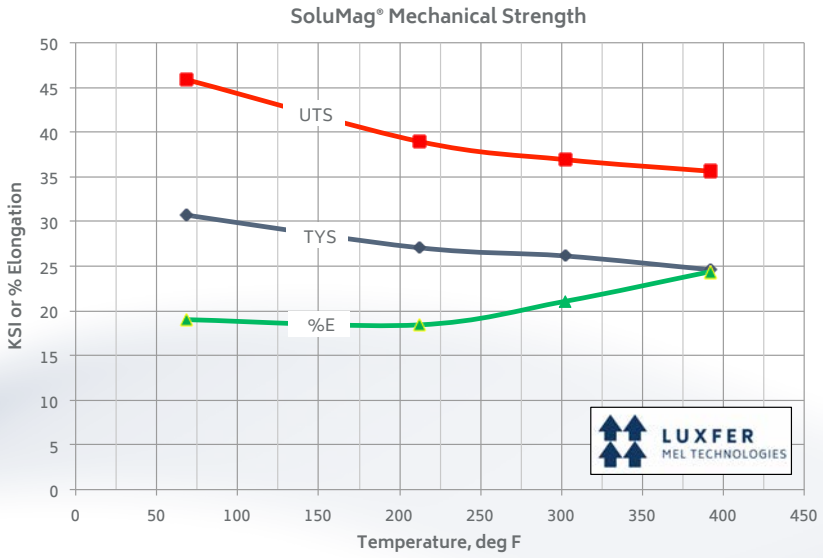
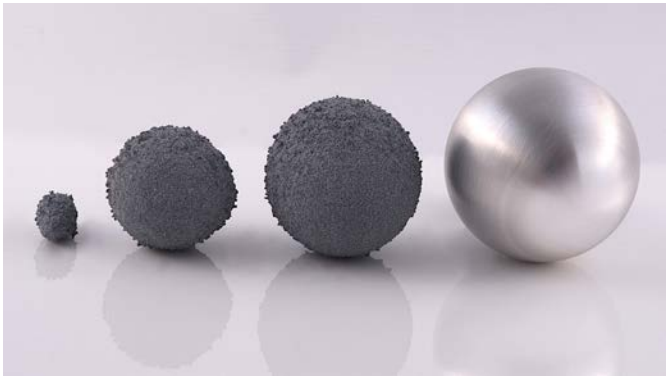


Chart 4. SoluMag 1100 mechanical properties at various temperatures.



SoluMag ball on seat performance

Luxfer MEL Technologies has done extensive testing of SoluMag magnesium alloy machined balls on cast iron seats to determine the holding pressure this material exhibits. Testing was done with ball diameters across the size range available and with various overlaps on the seat diameter to determine the role of diameter and overlap on the ball performance. From Chart 5 below, a 3.0″ diameter ball, using a 3.0% overlap seat (3.0/1.03 = 2.913″ seat diameter), will hold just over 8000 psi differential pressure. This is a maximum pressure the ball/seat combination experienced during the test. A de-rating of the maximum pressure experienced is recommended to account for downhole conditions. Using this graph to predict pressure holding capability of SoluMag balls can aid in design of completion tools.

SoluMag Coatings Experience

To protect SoluMag from corrosion during times when minimal corrosion is wanted or in acid conditions, coatings can be used to provide a barrier to the metal surface. Extensive coating testing has been done to find the adequate coatings for protection for a few hours or a few days in a variety of condition. The topic of coatings is broad and can't be covered here adequately. In general, coatings that are baked onto the surface tend to exhibit better protection than ambient air-dried coatings. There is no concern with heating the coated SoluMag material during the short bake cycle for a coating. Contact us to discuss specific coatings that can give the appropriate protection.

Bonding to SoluMag

In some assemblies using SoluMag, adhesive bonding can be used to attach other materials to this magnesium alloy. Significant work has been done by the auto industry to bond other metals and materials to magnesium alloys. The surface preparation is important as is the cure cycle for the adhesive. If bonding another metal to SoluMag, air dried and heat cured epoxies have been tested and found successful. If bonding a polymer material to SoluMag, heat may need to be avoided for fear of over-cooking the polymer. One or two-part epoxies have been tested and good solutions have been found that should work in a downhole application. Luxfer MEL Technologies can supply a list of adhesives that will work for SoluMag assemblies that require bonding.

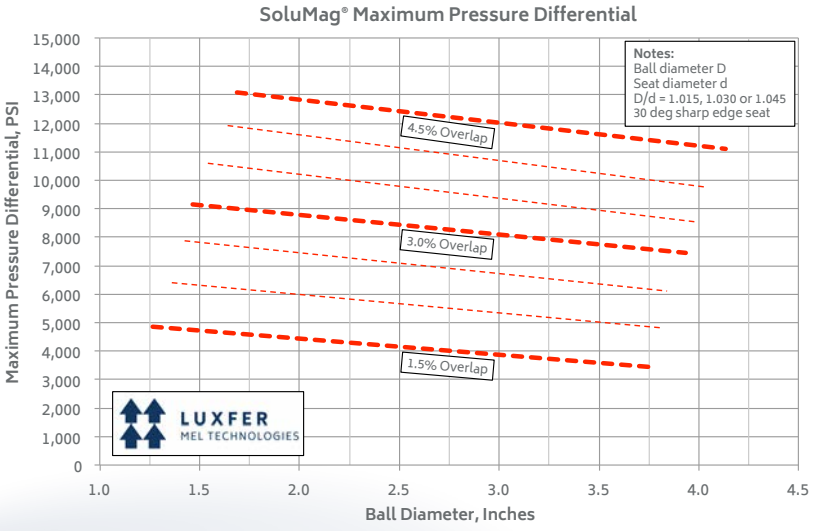


Chart 5. Maximum differential pressure for a SoluMag 1100 ball on a seat.

SoluMag ROHS Compliance

SoluMag magnesium alloy is compliant with RoHS. RoHS is the Restriction of the Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment (EEE) Directive. It limits the use of lead (Pb), cadmium (Cd), mercury (Hg), hexavalent chromium (Cr6+), polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE), in electronic systems. We have none of these materials in SoluMag magnesium alloy.

SoluMag Resistance to H_2S

Generally, all magnesium alloys have displayed resistance to corrosion by H_2S. This is due to the general chemical resistance of the MgS layer formed on the surface, the reaction product between magnesium and H_2S. SoluMag magnesium alloy is expected to have the same resistance to attack by H_2S.

Product details LINK

Further information

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† The information contained within is meant as a guideline only

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