# Healing of magnesium casting defects by flux-free soldering with Zn-based solders

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**Abstract:**

Often, magnesium die castings have such defects as local porosity, short-run, pouring defects, pin-holes, cracks, erosion scabs, not-complete formation of thin walls or profile, and others. Magnesium parts are subjected to phosphate pickling immediately after casting to protect against atmospheric corrosion. Repair of magnesium alloy casting by the flux brazing with the standard filler metal BMg-1 results in local melting of the base metal and the failure of phosphate coating. Two solders of Zn-Cu-Al and Zn-Cu-Al-Mg systems modified with grain refiners were used for healing casting defects by flux-free torch soldering in the temperature range of 400-500°C. Interaction between the solders and AZ91C base metal, microstructure of soldered joints, and protection from corrosion are among points of discussion.

## 0. Conventional solders suitable for magnesium cast repair

Magnesium alloys are considered as possible replacements for aluminum, plastics, and steels, primarily because of their higher ductility, greater toughness, and better castability. Many magnesium die cast articles are manufactured from the alloy AZ91C (Mg-8.7Al-0.7Zn-0.2Mn) having solidus temperature 468°C and liquidus of 568°C. Some of the cast articles are shown in Fig. 1. Other magnesium alloys made from such alloys as ZK51A, QE22A, or HK31A have solidus temperature above 550°C and manufactured by sand casting.

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The only one standard brazing filler metal BMg-1 (Mg-9Al-2Zn-0.2Mn) has solidus temperature 443°C and liquidus of 599°C [1]. This filler metal has close chemical composition to the cast alloy and, from this point of view, it looks ideal to repair casting defects. However, the BMg-1 cannot be used for repairing magnesium cast due to

liquidus temperature which is higher than both solidus and liquidus of the base metal. Therefore, soldering with the filler metals having liquidus temperature below 450°C was projected as a potential method for healing defects of magnesium casting.

Effective solders ZnMg3Al (Zn-3Mg-1Al) having melting range of 338-400°C (642-752°F) and Mg48Zn43Al9 (Mg-43Zn-9Al) having melting range of 340-348°C (644-660°F) were developed and tested by S. Muecklich, H. Klose, and B. Wielage for joining magnesium alloys that require low operational temperature [1, 2]. Both solders can be used for casting repair with special fluxes or with the assistance of ultrasound during the soldering operation. The solder Mg48Zn43Al9 showed better corrosion resistance than the alloy ZnMg3Al.


Fig. 1 Magnesium cast articles of AZ31C alloy have to be repaired

Prospective solders based on the system In-Mg-Al-Zn were developed by T. Watanabe et al. [3-5]. The best alloy of this system In-34.5Mg-0.8Al-0.2Zn exhibits liquidus at 476°C, brazing temperature 490°C, hardness 110 HV, and tensile strength of brazed joints comparable with the strength of 0.9 mm (0.036 inch) thick foil of the base metal - extruded alloy AZ31B. Addition of zinc up to 6.4 wt.% resulted in the decrease of melting point to 449°C, and also, in considerable decrease of tensile strength. Indium-based solders also require flux application, and besides, this alloys are now expensive after indium price had significant increase last years.

1. Zn-Al-Cu solders for magnesium casting repair

In order to find a cost-effective materials for magnesium cast repair by soldering, we tested two Zn-Al-Cu solders TiBraze®350 and TiBraze®330 (Table 1) which are used for aluminum casting repair by Great Western Technology, Inc., Troy, MI. These alloys have liquidus temperature below 400°C, and they can be micro-alloyed with grain-refining components such as niobium and zirconium [6]. The main advantage of these solders is application without a flux.

Table 1
Compositions of solders

| Solder | Composition, wt.% | Melting range, °C |
|---|---|---|
| TiBraze®Mg-330 | Zn-4Al-3Cu-0.2Nb/Zr | 330-380 |
| TiBraze®Mg-350 | Zn-8Al-4Cu-0.2Nb/Zr | 380-405 |

* Both solders are optionally alloyed with up to 0.2 wt.% of palladium to improve corrosion resistance of soldered parts

The solders were tested not only for repairing cast of magnesium alloys, but also for joining articles fabricated from magnesium matrix composites. Also, they can be used for joining such dissimilar base metals as wrought magnesium alloy parts to aluminum (for example, AZ31B to AA6061) or galvanized steel. Most applications do not require flux when brazing magnesium alloys with this filler metal in air.

These solders are not recommended for joining thin-wall structures due to its erosion activity to the base metal.

2. Soldering operation

The surfaces to be soldered should be prepared by degreasing of the surface by rubbing with acetone or gasoline; mechanical cleaning with steel brush or file; deep cast defects also should be mechanically treated with drill bits, metal wire brushes, or burr mills. Fig 2 shows two surface defects (open porosity) that were drilled out before soldering.

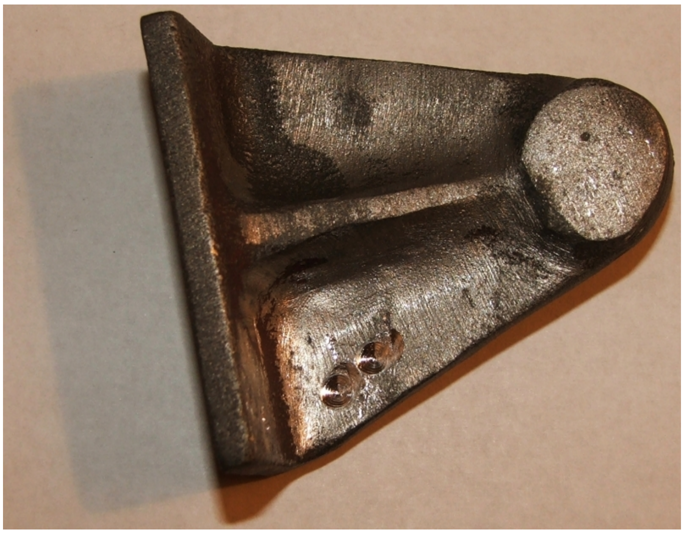

Fig. 2 A cast article with the defects prepared for soldering

Then, the surface to be repaired is heated by propane torch to the temperature in the range of 450-500°C for soldering with the TiBraze350, or 400-450°C for soldering with TiBraze330. Only after that, the solder rod is put in the flame and melted in the direct contact with the hot base metal. Rubbing movements are recommended to fill out the cast defects while the operator continues to heat the base metal. Soldered parts are slow cooled in air, without a fan or water. After the soldering, the cast article is treated by a file or abrasive in order to remove excessive solder from the surface.

Finally, repaired magnesium casting is again subjected to standard phosphate pickling in order to deposit a protective coating against atmospheric corrosion.

3. Structure of soldered joints

Study of macro- and microstructure (Fig. 3 and 4) showed that soldering with the TiBraze350 (Zn-8Al-4Cu-0.2Nb/Zr) is accompanied by a local partial re-melting of the base metal if die casting was made from AZ91C alloy. The re-melted base metal is solidified together with the solder, whereby a part of magnesium is transferred from the re-melted zone into the solder. Despite there were not found any cracks in the soldering area, obviously this solder cannot be recommended for healing casting defects of the AZ91C alloy.

The solder TiBraze330 (Zn-4Al-3Cu-0.2Nb/Zr) has lower soldering temperature, therefore cast articles of AZ91C alloy can be successfully repaired with this solder. The microstructure of soldered joints (Fig. 4) indicates no re-melting of the base metal. However, a training of soldering operator is needed even in this case in order to develop special skills for repairing magnesium casting.

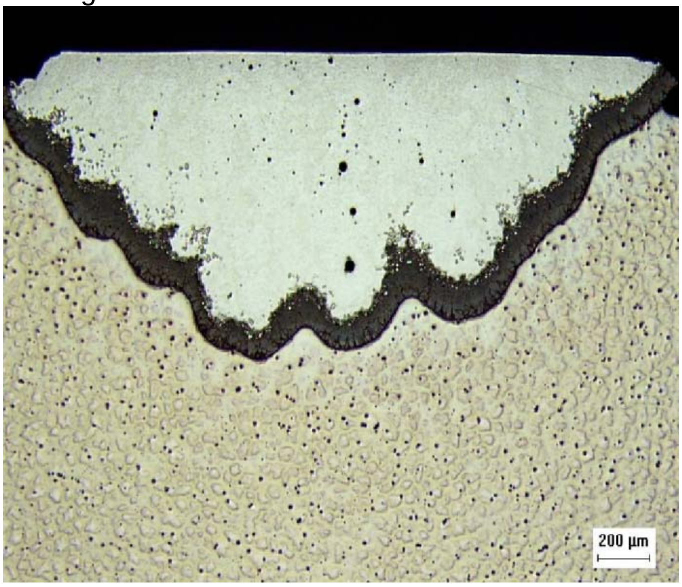

Fig. 3 The casting defect soldered with TiBraze350. The black interlayer is a partially re-melted and re-crystallized base metal - AZ91C alloy:
a - macrostructure

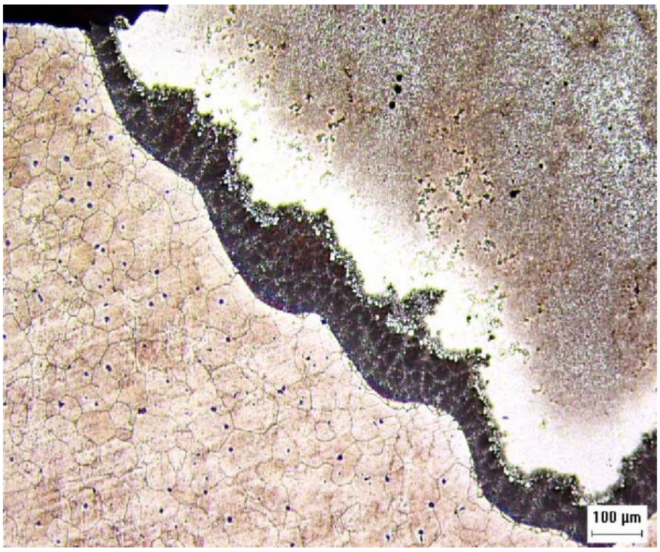

Fig. 3 b – microstructure. The white zone above the black interlayer is the zone enriched with magnesium from the base metal

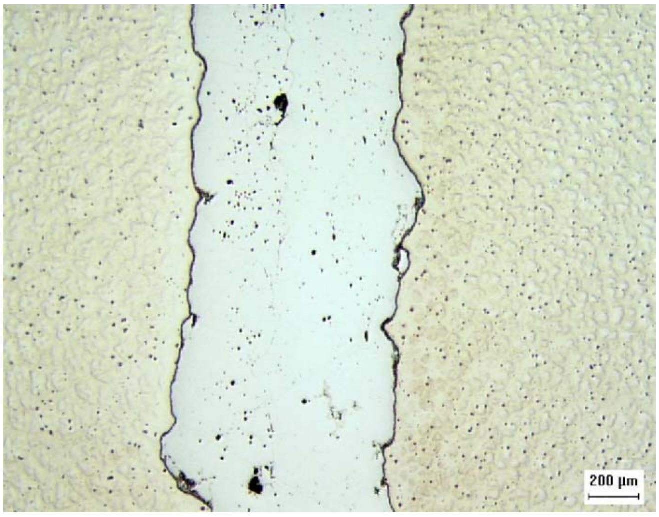

Fig. 4 Microstructure of soldered joint of AZ91C made with TiBraze330. No re-melted zone of the base metal

## 4. Conclusions

4.1 Magnesium cast articles can be repaired by flux-free soldering in air using solders based on the Zn-Al-Cu system. The solder Zn-4Al-3Cu is suitable for soldering casting made of the "low-solidus" AZ91C alloy, while the solder Zn-8Al-4Cu is suitable for healing casting made from such alloys as ZK51A, QE22A, or HK31A which have higher solidus temperature.

4.2. Torch soldering of the AZ91C cast alloy using the Zn-8Al-4Cu solder can be accompanied by local re-melting of the base metal. However, local re-melting and re-crystallizing of the base metal does not result in cracks or shrinkage in the repaired zone.


1. Muecklich S., Klose H., and Wielage B. 2003. Ultrasonic assisted brazing of magnesium, *Proc. of 2nd Int. Brazing/Soldering Conf., San Diego.*
2. Wielage B. and Muecklich S. 2003. Flux-free soldering of magnesium materials, *Welding and Cutting,* v. 55, No.4: 191-192.
3. Watanabe T., Komatu S., Yanagisawa A., and Konuma S. 2004. Development of flux and filler metal for brazing magnesium alloy AZ31B, *Yosetsu Gakkai Ronbunshu*, v. 22, No.1: 163-167.
4. Watanabe T., Komatsu S. and Oohara K. 2005. Development of Flux and Filler Metal for Brazing Magnesium Alloy AZ31B, *Welding Journal,* v. 84, No. 3: 37s-40s.
5. Watanabe T. 2004. Fluxes and brazes for brazing magnesium alloys, Japanese Pat. 2004050278.
6. Shapiro A.E. Microalloyed solders for joining and repairing aluminum and magnesium alloys, US Patent Application, 2006.