Breakthrough in Ultrasonic assisted industrial continuous casting

Ultrasonic continuous casting without centreline segregation, conventional degassing and grain refiners. By **Hélder Puga PhD*, Miodrag Prokic MSc**, Nico van Dongen MBA****

There are quite a few studies that acclaim the potential of ultrasonic technology for improving the quality of light metal products. Due to the limitations of conventional low frequency (pulsed) ultrasound, industrial upscaling was never realised, until today.

For 15 years, Swiss based Miodrag Prokic has been developing the Multi-frequency, Multimode, Modulated (MMM) ultrasonic DSP technology[1,2], which is able to eliminate standing waves and can be applied to (large volume) industrial molten metal processing such as aluminium and magnesium.

This article is about ultrasonically assisted continuous casting on a Bruno Presezzi Twin Roll caster and its effects on degassing, grain refinement, increased metal density and the disintegration of inclusions.

Challenges in production aluminium sheet

The MMM ultrasonic equipment was recently successfully tested and applied to a Twin Roll Casting Process (TRC) (**Fig 1**). Ultrasonic technology along with advantages of being elegant, clean, low cost, and easy to operate, is also highly-effective and energy saving (900 W in our trial) when it comes to traditional problems in the continuous casting process. The main problems in the conventional TRC process are coarse columnar grains, presenting strong chemical segregation at the centre of a strip as a consequence of large force, which is effectively welding two pre-solidified shells in the bite of two rolls[3]. Thus the solute-rich liquid is squeezed between the growing dendrite, promoting a considerable segregation in the central line. Furthermore, in some aluminium alloys such as Al-Mg-Mn, microstructural gradients and inhomogeneity inherently exist and cannot be eliminated by a simple modification of TRC processing parameters[4].

Industrially, the application of ultrasonic equipment based on MMM technology presents an effective way to overtake mentioned drawback limitations verified in the conventional TRC process. This novel compact ultrasonic equipment is characterised by the synchronisation of many vibrational modes through coupled

Fig 1. Dr. Hélder Puga (l) and Miodrag Prokic (r) during a recent trial.

*CT2M – Centre for Mechanical and Materials Technologies, University of Minho, 4800-058 Guimarães, Portugal
**ALUPRO-MPI Ultrasonics Inc., 2400 Le Locle, Switzerland (www.ultrasonicdegassing.com, www.ultrasonicmetallurgy.com,)

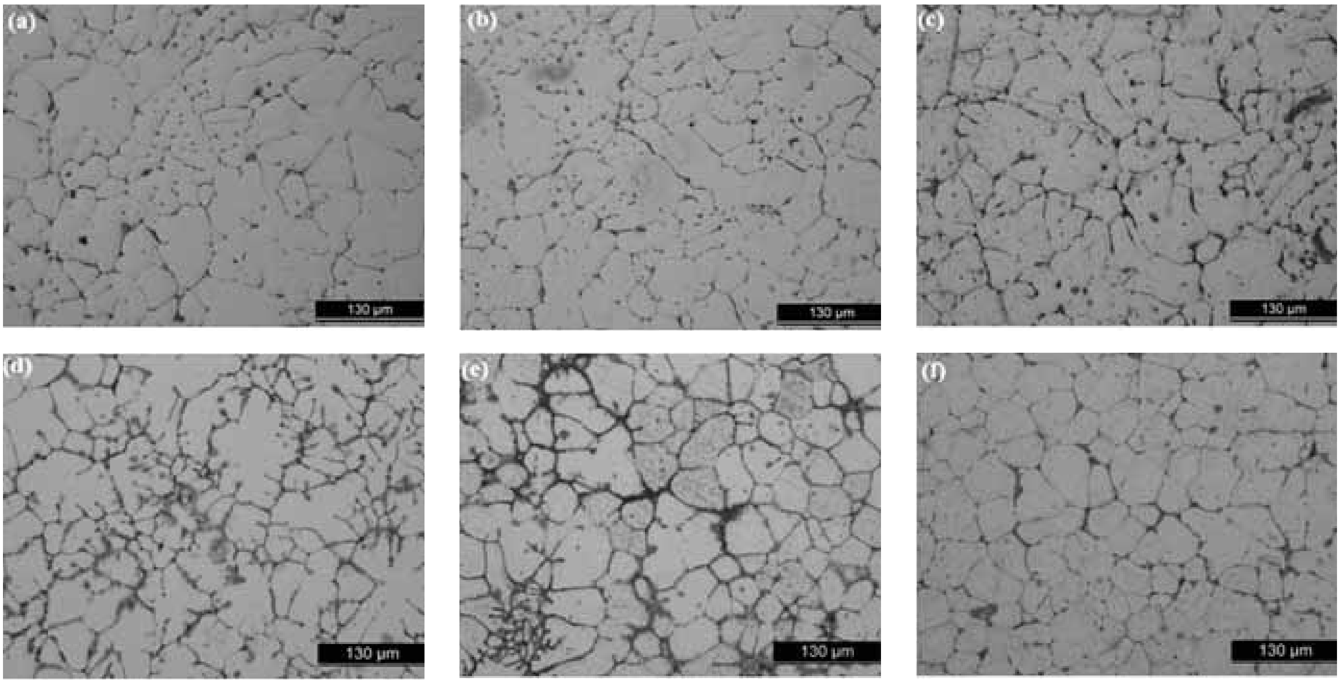

Fig 2. Effect of liquid temperature on the microstructure after casting Al-Mg-Mn: (a-c) with 1kg/ton of Al5Ti1B; (d-f) with MMM Ultrasonic Technology. (a) and (d) casting at 700ºC; (b) and (e) casting at 685ºC; (c) and (f) casting at 670ºC

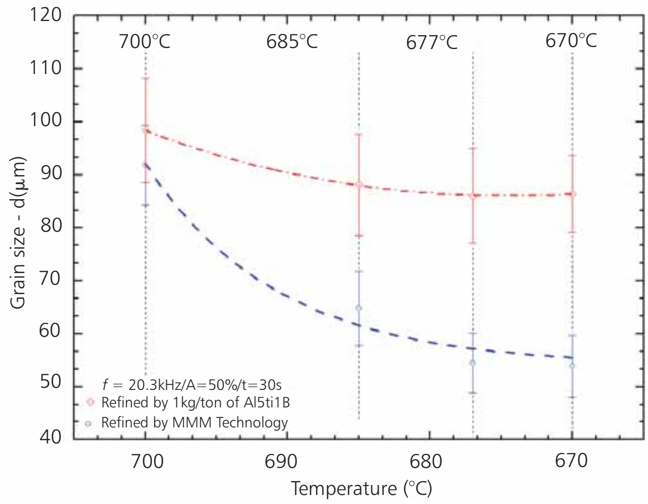

Fig 3. Effect of liquid temperature on the grain size after casting Al-Mg-Mn processed by differents methods

harmonics and sub-harmonics. It is essential to maintain high and stable ultrasonic vibrations in metal melt during processing, being very relevant for improving liquid metal refinement and modifications.

Microstructure and mechanical properties of TRC light metal

The efficiency of ultrasonic treatment (UST) depends on many factors, namely the ultrasonic parameters, such as amplitude and frequency of vibration, the degassing conditions (melt treatment temperature and processing time), the alloy composition, the material purity, and volume, all of great importance in the obtained results. Furthermore, due to the minor degree of deformation, normally present in a TRC strip, the macro and microstructure is strongly affected by the downstream processing of casting[4]. Therefore, a comprehensive understanding of the process and the interaction between the casting conditions and strip final quality is imperative for reaching high quality in TRC strip production.

The present study is based on results from two different trials in order to evaluate the effect of MMM technology on performances of Al-Mg-Mn alloy. First trial was conducted in a laboratory, which allowed quantifying the best melt temperature to reduce the grain size of α-Al.

Fig 2 presents the as-cast microstructure of the Al-Mg-Mn alloy processed by different refinement techniques at different temperatures. From **Fig 2** it is clear that UST had a significant effect on the microstructure morphology of the as-cast alloys and the final microstructure depends on the US treatment temperature, when compared with microstructure obtained after conventional treatment (refinement with 1kg/ton of Al5Ti1B).

The average α-Al grain size was plotted and is presented in **Fig 3**. It is clear that for a given refinement process, decreasing melting temperature promotes grain refinement, however the best results were obtained for the alloy refinement by MMM technology. **Fig 3** also suggests that, although the efficiency of grain refinement increased with decreasing of melt temperature, such increase was not linear, and the reduction in grain size became less effective after reaching a certain temperature level, which depends on the processing temperature.

The second trial was conducted on an industrial scale using the same alloy, according to the experimental results obtained in laboratorial scale. **Fig 4** shows the contrasts of electronic microscopy microstructure of samples processed by traditional process (degassing by argon and refinement by addition of 1kg/ton of Al5Ti1B) (**Fig 4(a)**) and processed by MMM technology (regarding degassing and refinement) (**Fig 4(b)**). **Fig 4(a)** shows the microstructure of the cross-section of alloy in which is clearly observed centre zone segregation.

Besides the strong chemical segregation at the centre of the strip (**Fig 4(a)**) and the crystals homogeneously distributed (Fig. 4(b)), the SEM analysis revealed the co-existence of other intermetallic phases, as presented in **Fig 5**, which morphology, EDS X-ray spectra suggest presence of the composition of AlMnFeSi. However, only a careful investigation of the AlFeMnSi type of particles composition would give a definitive answer regarding such particles. When compared with the microstructure of the non-US processed samples (conventional process), the phases present in the US-treated samples (**Fig 5(b)**) revealed a more uniform distribution, and their morphologies were significantly different.

According to **Fig 6** it is clear that is possible to increase alloy mechanical properties with a correct melt treatment, especially when ultrasonic treatment with MMM technology is applied (Test 3). These results are according to good homogenisation of microstructure morphology and low level of porosity verified in the samples tested. Also, these results are according to a bibliograph where it is mentioned that mechanical properties of Al alloys depend on several factors, namely to microstructure morphology and size and distribution of porosities [5,6].

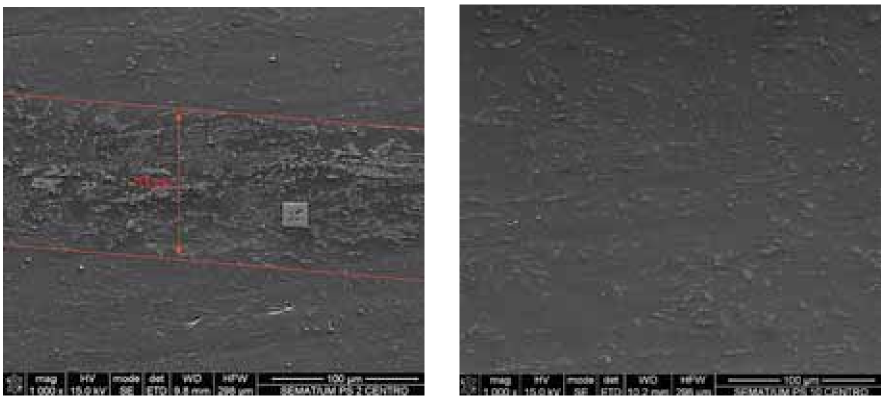

Fig 4. Chemical segregation at the centre of the strip. (a) Conventional processing; (b) after application of MMM technology.

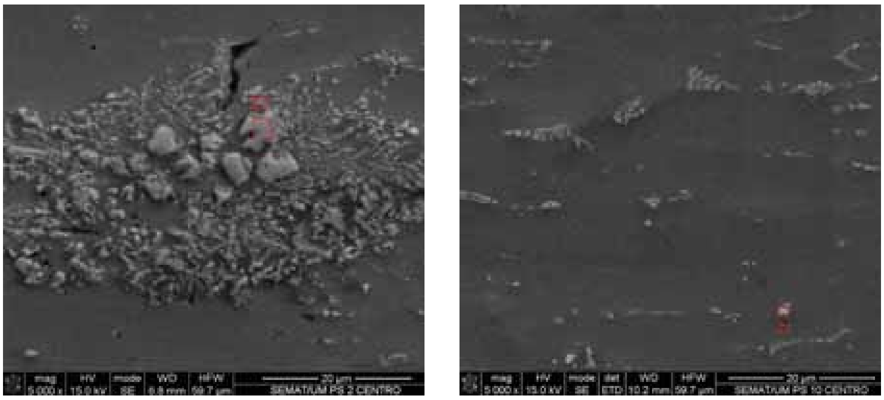

Fig 5. SEM images of the Al-Mg-Mn alloy revealing the presence of AlFeMnSi particles in: (a) traditional processing; (b) US treatment.

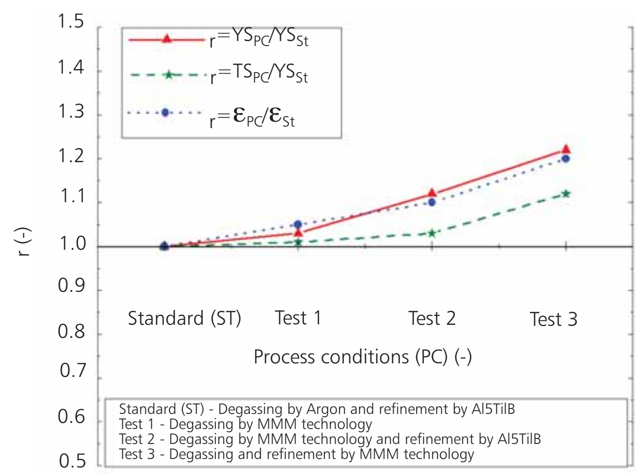

Fig 6. Relation of mechanical properties of strips of Al-Mg-Zn alloy after twin-roll casting.

Conclusions

The combination of technological operations like a TRC with MMM technology allows:

(1) Elimination of traditional argon degassing and replacement with ultrasonic degassing (savings in argon and electricity for mixing).

(2) Elimination of the use of standard master alloy additives (just ultrasonic processing is producing equivalent or better results).

(3) Better alloying, wetting, disintegration, homogenisation and integration of all metallic and non-metallic ingredients and impurities into a metal mass (we get: more homogenous, harder, no defect, no intermetallic long needle). ■

References

[1] European Patent Application (related to MMM technology): EP 1 238 715 A1 Multifrequency ultrasonic structural actuator. Prokic Miodrag, MP Interconsulting. (2001).

[2] H. Feng et al. (eds.), Ultrasound Technologies for Food and Bioprocessing, Food Engineering Series, DOI 10.1007/978-1-4419-7472-3_5. Chapter 5 Wideband Multi-frequency, Multimode, and Modulated (MMM) Ultrasonic Technology (author M. Prokic). Springer Science+Business Media, LLC 2011.

[3] Bian Z., Bayandorian I., Zhang H. W., & Fan Z. Twin Roll Casting and Melt Conditioned Twin-Roll Casting of Magnesium Alloys. Solid State Phenomena. 141-143, 195-200 (2008).

[4] Dorner-Reisel A.Twin-roll casting of light metals and composite materials for light weight application. Aluminium 11, 60-65 (2012).

[5] Sun N., Patterson R. B., Suni P. J., Simielli A. E., Weiland H., & Allard F. L. Microstructural evolution in twin roll cast AA3105 during homogenisation. Materials Science Engineering A. 4416, 232-239 (2006).

[6] Panusková M., Tillová E., & Chalupová M. Relation Between Mechanical Properties and Microstruture of Aluminium Allooy AlSi9Cu3. Strength of Materials 40(1), 98-101 (2008).

[7] Li Y.M., & R.D.Li. Effect of the casting process variables on microporosity and mechanical properties in an investment cast aluminium alloy. Science and Technology of Advanced Materials. 2, 277-280 (2001).