MMM – Liquid Metals Processing

(Sonocrystallization & Sonochemistry)

European Patent Application (related to MMM technology):
EP 1 238 715 A1
Multifrequency ultrasonic structural actuator
Applicant: Prokic Miodrag, MP Interconsulting, 5.03.2001 – 11.09.2002

DISPOSITIF POUR LA GENERATION D'ONDES ULTRASONORES
Inventeurs : Prokic Miodrag et Jean Claude Padoy
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European Patent Application: EP 1 060 798 A1
Unidirectional single piston ultrasonic transducer
Applicant: Prokic Miodrag, MP Interconsulting, 8.06.1999 – 20.12.2000

Books:
Miodrag Prokic, Piezoelectric Transducers Modeling and Characterization. 240 pages, January 2004, MPI, Le Locle, Switzerland

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

1. ***MMM (=) Multimode-Modulated-Multifrequency, based on advanced signal processing techniques***, applicable in real time, during ultrasonic operation.
2. MMM ultrasonic agitation of liquids (including liquid metals) is on some way ***synchronously activating and maintaining different vibrating modes*** of liquid molecules (even on long distances from the MMM source).
3. ***MMM ultrasonic agitation is creating uniform and high density, spatial distribution of sonic and ultrasonic activity in liquids (without creating standing waves).***
4. MMM activated liquid state presents special vibrating and cavitating state of liquids, which is phenomenologically and technologically very rich and powerful (at least for order of magnitude faster, more productive and efficient, compared to fixed-frequency ultrasonic liquids processing).
5. MMM ultrasonic agitation is also creating "***wideband white-noise cavitation***" (with different cavitating bubbles, related to different frequencies), and such large spectrum cavitation is also synchronously agitating and maintaining different vibrating modes of liquid molecules on long distances from the source.
6. ***There is certain (not very short), residual life of such molecular vibratory states, after ultrasonic source is switched OFF***.
7. Mentioned ***vibratory molecular modes are propagating (on relatively long distances from the MMM source)*** along liquid channels and conduits, which can be very much curvilinear, zigzag, or spiral and irregular. ***If MMM ultrasonic source is permanently active (switched ON), it can feed and keep (or maintain) activated molecular states on a very long distances, and in a very large containers and channels***.

8. Mentioned ***MMM-activated molecular states are producing effects of: degassing, homogenization, wetting, capillary penetrations, uniform micro-crystallization and grain refinements, filtering… temporarily reducing viscosity and increasing fluidity*** of liquids and liquid metals …
9. ***Liquid fluidity can be increased 3 to 5 times (meaning viscosity is significantly reduced) during MMM ultrasonic excitation of liquids, including liquid metals***.
10. MMM vibrations can be produced only with ultrasonic transducers, sonotrodes and solid structures that are accepting MMM modulation (meaning with conveniently designed, FEA optimized, and sufficiently mechanically flexible objects, plates, tubes, containers and membranes). We have relatively small, lightweight, modular and flexible ultrasonic systems for any metallurgical application.
11. ***Sonocrystallization, degassing, homogenization etc. are effects of ultrasonic fields known, mutually analog, and valid for any liquid, including liquid metals***. Under MMM ultrasonic activity, mentioned effects in liquids are accelerated and magnified for orders of magnitudes.
12. ***Constant or fixed frequency ultrasonic vibrations are creating harmonic (or sinusoidal) waves, making spatially non uniform, periodical and not very efficient, standing waves distribution of acoustic activity***. This is the principal reason why spatially uniform MMM ultrasonic agitation is better for liquids and liquid metal processing, compared to any other fixed-frequency method (known from our competitors).
13. **MMM technology** applied to non-ferrous alloys' melt treatment can produce metals purification, microstructure refinement, structure modification and degassing, based on the specifically created acoustic field introduced in a molten metal in order to create spatially and uniformly well distributed and wideband multi-frequency cavitation.
14. When a liquid metal is submitted to high intensity ultrasonic vibrations, the alternating pressure above the cavitation threshold creates numerous cavities in the liquid metal promoting two effects.

    (1) Degassing effect: the cavitation achieved by application of *MMM technology* intensifies mass transfer processes and accelerates the diffusion of hydrogen from the melt to the developed bubbles. As acoustic cavitation progresses with time, adjacent bubbles touch and coalesce, growing to a size sufficient to allow them to rise up through the liquid, against gravity, until reaching surface.

    (2) Microstructure refinement and modification effect: the alternating pressure achieved by application of *MMM technology*, above the cavitation threshold is promoting numerous of low pressure (almost vacuum) bubbles in a liquid metal, which start growing, pulsing with a continuous expansion/compression regime and finally collapse. During expansion, bubbles absorb energy in the melt, undercooling the liquid at the bubble-liquid interface, resulting in nucleation on the bubble surface. When bubbles collapse acoustic streaming develops in the melt, distributing the nuclei into the surrounding liquid producing a significant number of nuclei in the molten alloy, thus promoting heterogeneous nucleation.

15. **MMM technology -** The reliable technique for melt treatment was developed and applied in different non-ferrous alloys. Based on the results achieved from different alloys and according to results obtained in a laboratory and industrial scale, the main conclusions that can be drawn are:

    (1) Ultrasonic degassing can be an efficient process to degas molten non-ferrous alloys. For melting charges (on industrial scale) acceptable degassing is achieved after 2 minutes ultrasonic treatment, although after 1 min the alloy density is already up to 90% of the maximal value.

    (2) When compared with the traditional fixed-frequency ultrasonic sources MMM ultrasonic technique seems to improve significantly the ultrasonic degassing process by increasing the final alloy density and degassing rate.

    (3) Ultrasonic processing by MMM technology is an external supply of energy – presenting physical process - environmentally clean and efficient that promotes refinement of primary grains, intermetallic phases, modification of eutectic Si and a decrease of porosity in non-ferrous alloys.

    (4) Ultrasonic treatment clearly improves mechanical properties and the fluidity of treated alloys. *Treatment of aluminium amd magnesium alloys is not only related to degassing... there are much more important aspects of ultrasonic processing like metal refinement, liquid homogenization, eutectic silicon modification and intermetallic refinement modification.*

    Best degassing can be realized on higher melt temperatures, and best grain refinement can be realized on lower temperatures. Consequently, very good degassing and very good grain refinement cannot be realized in the same time, in the same space, and using the same ultrasonic system. Thanks to MMM technology, we can realize very good degassing and grain refinement in the same time, using the same ultrasonic system, while melt temperature is evolving.

    Very good degassing will improve mechanical properties of casted metal, but it can never achieve mechanical properties of casted metals when degassing, grain refinement, intermetallics refinement.... are realized in the same time, and this is the stength of MMM technology.

PUBLICATIONS - REFERENCES

[1] H. Puga, J. Barbosa, E. Seabra, S. Ribeiro, M. Prokic - The influence of processing parameters on the ultrasonic degassing of molten AlSi9Cu3 aluminium alloy. Materials Letters, Vol. 63, pp. 806-808, 2009.

CT2M - Centre for Mechanical and Materials Technologies, University of Minho, Portugal
MP Interconsulting, Le Locle, Switzerland

http://www.sciencedirect.com/science/article/pii/S0167577X09000330

[2] H. Puga, J. C. Teixeira, J. Barbosa, E. Seabra, S. Ribeiro, M. Prokic – The combined effect of melt stirring and ultrasonic agitation on the degassing efficiency of AlSi9Cu3 alloy. Materials Letters, Vol. 63, pp. 2089-2092, 2009.

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http://www.sciencedirect.com/science/article/pii/S0167577X09004972

[3] H. Puga, S. Costa, J. Barbosa, S. Ribeiro, M. Prokic - Influence of ultrasonic melt treatment on microstructure and properties of AlSi9Cu3 alloy. Journal of Materials Processing Technology, Vol. 211, pp. 1729-1735, 2011.

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http://www.sciencedirect.com/science/article/pii/S0924013611001452

[4] H. Puga, J. Barbosa, S. Costa, S. Ribeiro, A.M.P.Pinto, M. Prokic - Influence of indirect ultrasonic vibration on the microstructure and mechanical behavior of Al-Si-Cu alloy. Materials Science and Engineering A, Vol. 560, pp. 589-595, 2013.

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http://www.sciencedirect.com/science/article/pii/S0921509312014207