The metal treatment station combining flux injection and rotary degassing

Rotary degassing, the introduction of an inert purge gas through a spinning impellor, has become a widespread practice in the aluminum foundry industry for the efficient removal of dissolved hydrogen from molten aluminum. Foseco's Mobile Degassing Unit (MDU) has established a standard for rapid and efficient degassing since its introduction in the 1980s.

In recent years, the introduction of a flux through such a rotary system has gained some popularity in the industry as a means to combine degassing with metal cleaning, removing dross and non-metallic inclusions suspended in the melt.

While rotary degassing, by introducing purge gases as a cloud of finely divided bubbles, has demonstrated its effectiveness in improving metal cleanliness by floating inclusions out of the melt, it has been suggested that cleanliness could be further improved by the addition of a flux along with the inert purge gas.

With the aim of developing a Metal Treatment Station (MTS), combining flux injection and rotary degassing in a single unit, Foseco initiated trials at a production foundry in the US to compare the effectiveness of such a combination with that of rotary degassing alone.

Several questions needed to be answered:

- Could the standard MDU perform the same (in both hydrogen removal and metal cleanliness) as an MTS if the purge gas flow rate was the same?
- Does rotor design affect the performance of rotary flux injection?
- Can the propensity of such flux injection systems to plug be avoided?
- Are flux injection systems cost-effective?
- Can quantifiable differences between the systems be demonstrated?

Multiple tests were carried out on three foundry alloys: A356, A357 and C355. To reduce the variables in the variety of tests conducted, the same operator was used to perform all the procedures. All auxiliary treatments (e.g. heat treatment of tensile test bars) were done at the same time. Additionally,

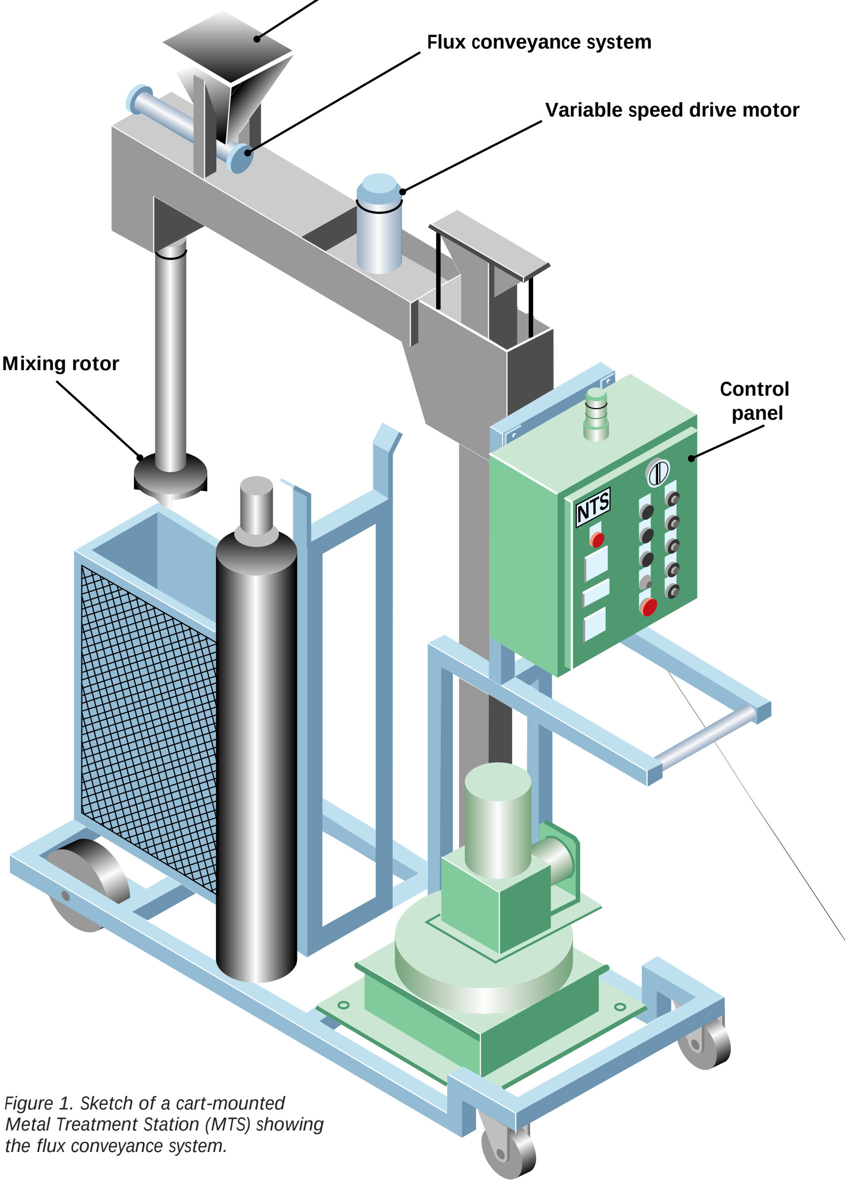

Figure 1. Sketch of a cart-mounted Metal Treatment Station (MTS) showing the flux conveyance system.

all operating parameters, for example rotor speed, gas flow rate, cycle time, and amount of metal treated were kept the same for both units tested (MDU and MTS).

A drawing of the MTS – figure 1 – and photo of the unit in operation – figure 2 – are provided. The unit has the ability to introduce flux and purge gas down the center of a rotating graphite shaft without plugging.

Keys to the system are a vibratory flux conveyance system and a specially-formulated granulated flux. The system moves the flux horizontally through a conveyor tube until it reaches the gas insertion point. The flux is then forced down a static tube, which prevents centrifugal forces on the flux, and into the rotating graphite shaft, lined with an insulating material to prevent premature melting of the flux, a contributor to plugging. A modified 'mixing' rotor was also developed to increase performance of the system while avoiding rotor blockage from fused flux.

Test objectives

The primary objective was to determine if the addition of flux via the MTS would yield a higher metal quality – measured by both cleanliness and gas levels – compared to an MDU without the addition of flux.

A secondary objective was to see whether the MTS equipment could stand up to the rigors of a production foundry environment without malfunction or plugging.

A series of standard tests used in the aluminum foundry industry were run. Samples were taken both immediately before and immediately after treatment of the metal with both the MDU and MTS. These tests were:

Figure 2. The MTS in operation.

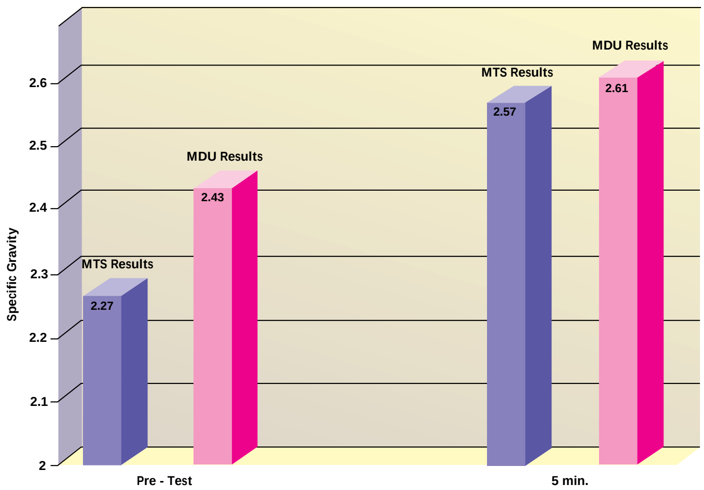

Figure 3. Alloy A356 MTS vs MDU specific gravity results.

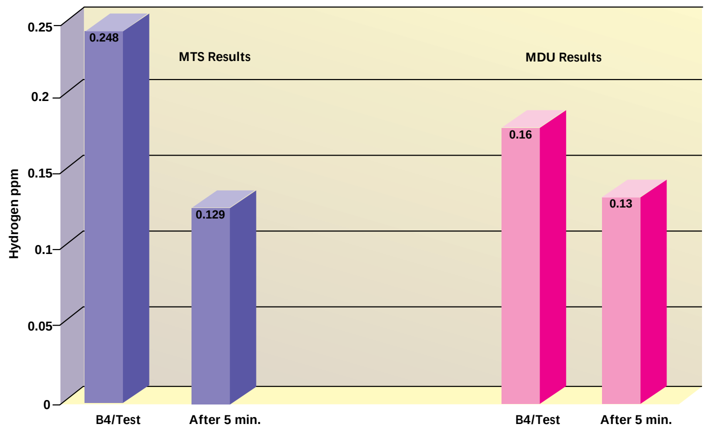

Figure 4. Alloy A356 hydrogen analysis results.

Specific gravity

This common technique to determine the level of dissolved hydrogen in a melt was already in use at the foundry as a 'go, no go' criterion before pouring any batch of metal. A sample is solidified in a reduced pressure testing device, then weighed in air and in water. The weight difference is then divided by the weight in air to arrive at a value for specific gravity.

Hydrogen analysis

The Ransley Mold method was used. Samples were cast in a chill mold, then machined and analyzed on a Leco RH402 hydrogen determinator. Two analyses were run from each sample. Each consisted of both a bulk and surface component reported in parts per million. The total hydrogen content reported was the sum of these components.

Mechanical properties

Standard test bars were poured, machined, and pulled to determine tensile strength, yield strength, and percent elongation. The test results are used as an indication of metal cleanliness.

K-Mold inclusion determination

This notched bar fracture test is becoming more common in the industry. Bars are cast in a standard mold, then fractured at four notched locations. Visual interpretation of inclusion count is done on the fracture faces. Such interpretation is highly operator-dependent, and it becomes more difficult as the tested metal becomes cleaner. Five samples for each test were used to reduce of the variability inherent in the procedure.

Metallic content of the dross

A high percentage of metallic aluminum in the dross skimmed from the top of the melt means that the foundry is losing valuable metal by sending it to a dross reclaimer at a significantly reduced value. Dross samples were skimmed and analyzed for metallic aluminum content via the hydrogen evolution method.

Chemical analysis

Samples were analyzed spectrographically to ensure that magnesium and strontium levels in the metal were maintained within the foundry's specified range and were not adversely affected by the application of the flux.

Results

Because tests were run in a production environment, rather than a research laboratory, it was impossible to expect to have the same starting point for each parameter tested. Over the course of the weeks of testing, metal conditions – for example charge make-up – temperatures, and humidity varied. The graphical results shown are averages of the series of tests.

As previously noted, the foundry used a minimum specific gravity value as the criterion for acceptability for pouring a heat. Both the MDU (using inert gas degassing alone) and the MTS (using a one-minute flux injection cycle and four minutes of inert gas degassing) could consistently meet the criterion, so comparisons between the two systems were made at the five-minute checkpoint.

Both the MDU- and MTS-treated heats showed increases in the specific gravity after treatment for all the alloys tested. Figure 3 is typical, showing the results of tests on alloy A356 heats, which suggest that the effects of the two processes are essentially the same. This would certainly seem to indicate that the addition of flux through the MTS does not enhance hydrogen removal compared to standard rotary degassing, at least when the gas flow rates in the two processes are kept the same.

Figure 4 shows the results of the hydrogen analyses done on the A356 heats, confirming the basis of the specific gravity increases shown in figure 3 and demonstrating again that the effects of the two processes are essentially the same.

Both MDU- and MTS-treated heats showed slight improvements in mechanical properties following treatment. Figure 5 and 6 show the tensile and yield strength results for the C355 heats, while figure 7 shows the results of tests of percent elongation for the A356 heats.

It should be noted that the values for tensile and yield strengths and elongation were already above the specified minimum (standard) in the pre-treatment specimens. Still, given a premise that improved metal cleanliness will result in an increase in mechanical properties, one would expect that the MTS-treated metal would produce superior results. The results seem to indicate that the addition of flux, while certainly not adversely affecting mechanical properties, does not provide significant improvement beyond that provided by good rotary degassing practice.

A marked difference in metal cleanliness between MDU- and MTS-treated heats was demonstrated in the results of the K-Mold testing. For each alloy tested, the MTS-treated metal showed a much greater reduction in inclusion count versus the pre-treatment level than was the case with rotary degassing alone. Figure 8 shows the results for A356 alloy (where MTS treatment gave a 41% reduction in inclusions while degassing alone gave a 25% reduction) and for C355 alloy (where the corresponding reductions are 64% and 34%).

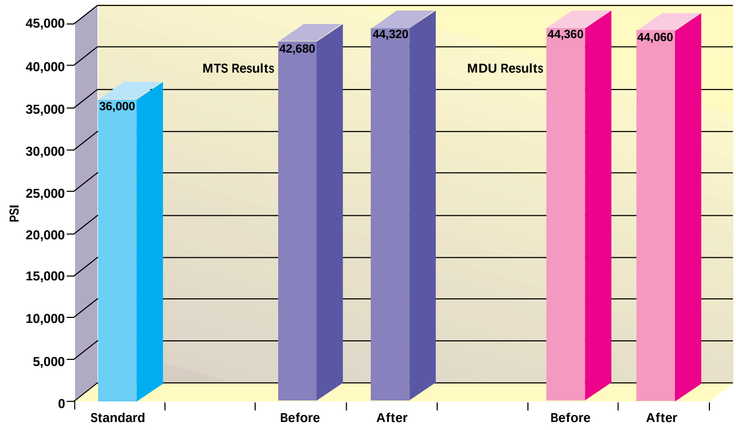

Figure 5. Alloy C355 tensile strength results.

Spectrographic analysis for both MDU- and MTS-treated heats showed similar decreases (fading) in strontium and magnesium levels, though both treatments kept the chemistry within the foundry's specification limits – see figures 9 and 10. These results did show that the addition of a flux did not adversely affect the chemical composition of the metal.

The most dramatic difference between MDU- and MTS-treated metal was shown in tests for metallic content of the dross – see figure 11. For each alloy tested, the MTS-treated metal showed a 20-40% decrease in metallic aluminum in the dross versus the dross obtained from heats treated by rotary degassing alone.

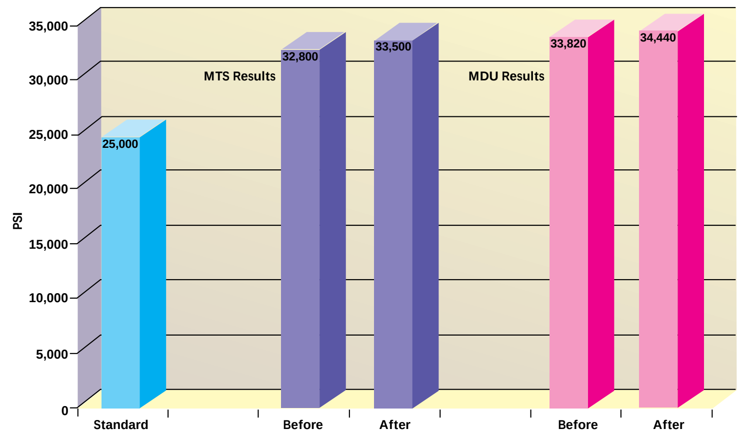

Figure 6. Alloy C355 yield strength results.

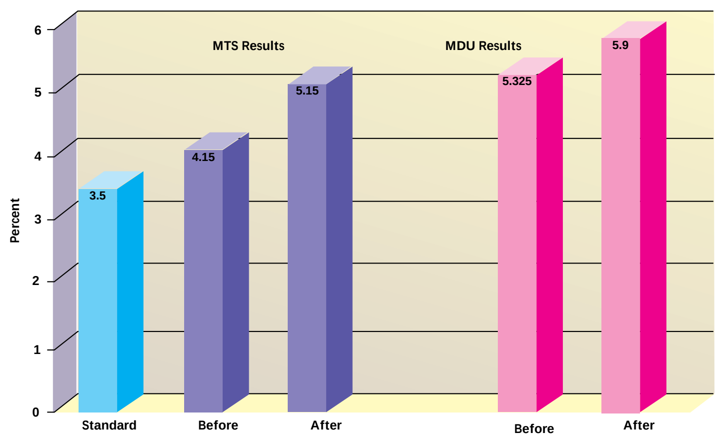

Figure 7. Alloy A356 percent elongation results.

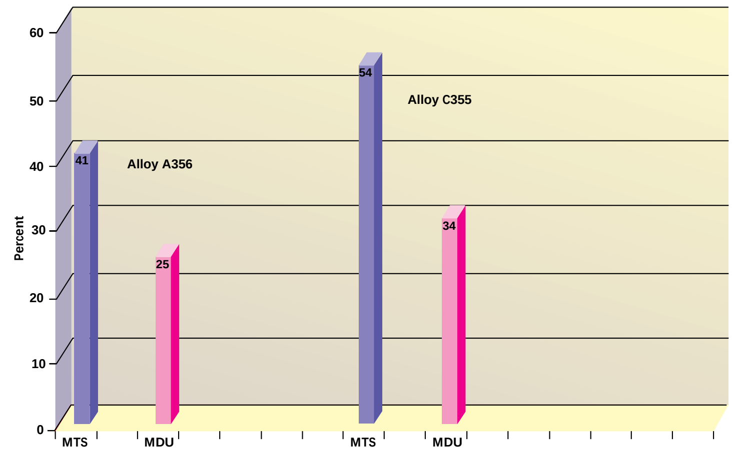

Figure 8. K-Mold inclusion removal rate, pre-treatment to post-treatment.

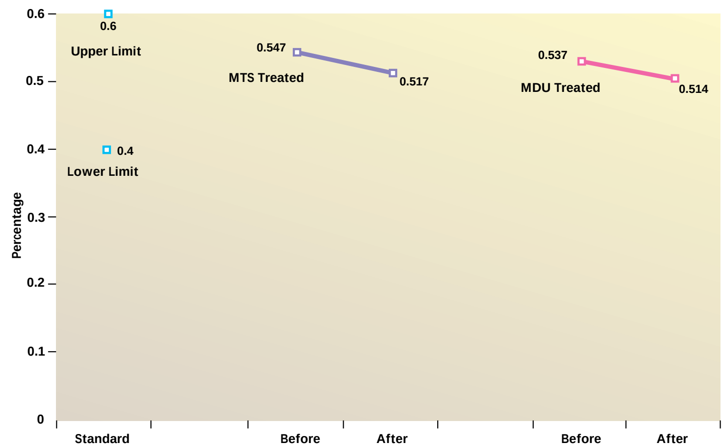

Figure 9. Alloy C355 magnesium levels.

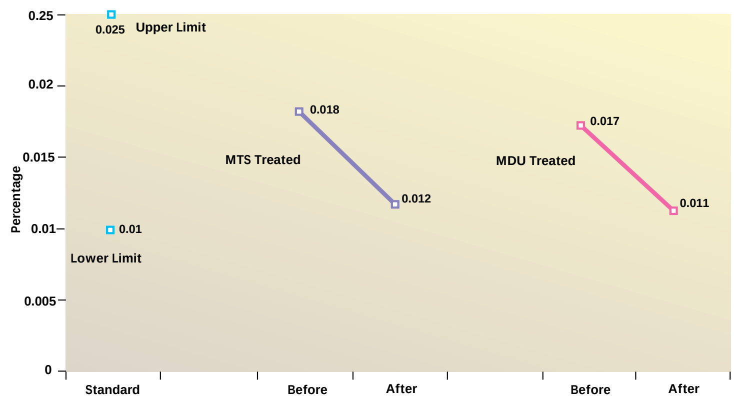

Figure 10. Alloy C355 strontium levels.

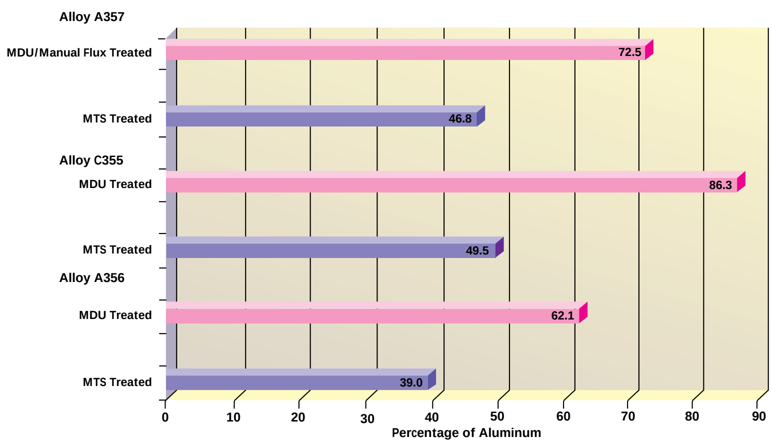

Figure 11. Metallic aluminum content in the dross after treatment.

Areas for further development

With most of the initial questions concerning the MTS successfully addressed, several areas will require further development.

For example, the five-minute checkpoint was arbitrarily selected according to the foundry's criteria. Since high-quality results have been demonstrated in five minutes, further work will determine whether a shorter time could produce similar results.

The granulated flux used was shown to be very effective in the MTS system. Further work will look at several other chemical compositions for granulated fluxes to optimize the results.

Purge gas flow rates were selected on the basis of flow rates used by other flux injection systems. Because the patented flux delivery system incorporated in the MTS prevents flux from adhering to the inside of the graphite shaft, future tests will be run at lower gas flow rates.

The tests reported were run in batch-type treatments on individual furnaces. A trend toward the installation of rotary degassing units for continuous operation at the dip-out well of reverberatory furnaces and in launder systems suggests that the MTS will become a part of such installations. Since the patented flux delivery system should prevent shaft plugging, further work will be needed on continuous treatment systems.

As noted above, for this series of tests, the MTS was set to introduce flux during the first minute of its five-minute operation to correlate with the results from a five-minute MDU cycle. Work following the conclusion of these tests introduced the flux over a span of five minutes (though the total amount of flux introduced was unchanged) with a subsequent degassing cycle. Preliminary results indicate that the following benefits can be achieved:

- Still lower metallic aluminum in the dross (further reductions of 15-25%).
- Higher percentages of inclusion removal (50-60% reported).
- Greater improvements in mechanical properties.

Summary and conclusions

Flux injection with the MTS system produces cleaner aluminum – fewer inclusions – than does rotary degassing alone. It also provides the opportunity for significant savings by dramatically reducing the percentage of metallic aluminum contained in the dross skimmed from the melt.

The robustness of the MTS equipment and its resistance to plugging was verified over the four-month course of these tests.