

# Copper Infiltration Using Wrought Wire Infiltrant—Process and Productivity Improvements for Automotive Components

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## ABSTRACT

As the PM industry continues to introduce new, higher performance materials and processes, a bold new approach to copper infiltration has impacted the use of this mature PM process technology. A new, wrought copper alloy wire product offers an excellent infiltration response for both the standard FX-1008 PM steel grade as well with low alloy and tool steel grades. A complete set of mechanical properties for several levels of infiltrant and skeletal densities are provided. Comparisons with conventional compacted powdered infiltrant and property data published in MPIF Standard 35 are also offered. The processing advantages and productivity improvements associated with this new infiltration technology, as compared to the more conventional infiltration methods using powdered performs are discussed. The impact of this technology on two automotive component examples products are provided.

## INTRODUCTION

Copper infiltration of porous ferrous compacts, also known as the iron matrix or skeleton, has been popular in the North American market for over 60 years as a method to reduce the porosity and increase the strength of PM steel components. In this process the porous ferrous compact is brought into intimate contact with a copper base alloy and the two components are sintered at a temperature whereby the copper alloy melts and infiltrates the porosity of the ferrous compact [Ref 1, 2, 3, 4]. The ferrous compact may be in the green or sintered condition. If in the green condition this process is known as one-step infiltration or “sintration”. While better dimensional control is typically associated with the two-step infiltration process (sinter the ferrous compact first and then infiltrate) the one-step process is most popular for its lower processing cost. The copper infiltrant typically has been a specially formulated powder material compacted into the shape of a disc, wafer, slug or ring, suitably placed on the top or underneath the ferrous

compact during sintering. The assembly is placed on a sinter tray, typically a graphite or ceramic plate, to support the assembly and prevent molten copper from possibly dripping on the sintering belt and causing damage.

The molten copper is drawn into the interconnected pores of the ferrous matrix by capillary action. The capillary pressure varies inversely with pore diameter and directly with the surface energy of the infiltrating liquid and the contact angle. Therefore the infiltrating alloy should be designed to have good wettability and fluidity, low surface energy (limited solubility of the two materials or formation of an intermediate phase). Since smaller pores have greater capillary force these are filled first and more completely than larger pores.

When there is some mutual solubility of the matrix into the infiltrant, as in the case of iron and copper, the infiltrant composition is modified to limit the dissolution of the matrix by matching the equilibrium composition of the infiltrant to that of the matrix at the infiltrating temperature. Most commercial powdered infiltrants contain several weight percent iron to minimize erosion during infiltration. In addition it is generally desirable to limit the effects of the mutual solubility by keeping the infiltration time period short and the infiltration temperature sufficiently low. Finally it is extremely important that the surface of the ferrous matrix be clean, oxide-free and soot-free to ensure proper wetting by the molten infiltrant.

Ferrous PM components are copper infiltrated in order to improve physical or mechanical properties as noted below [1].

- Tensile strength, ductility and impact resistance
- Improved machinability
- Improved thermal conductivity
- Provide pressure tightness for leak-free operation in hydraulic applications

Seal porosity for secondary operations such as plating

Selective property improvement through localized infiltration

In 2005 Ultra Infiltrant introduced a new copper infiltration product based on a wrought copper alloy system (patent pending). This fully prealloyed wire product is supplied cut to length or coiled for precise size and weight control for ease of placement with the ferrous matrix. The rigid wrought infiltrant preform allows for ease of handling, precise placement and 100% product usage. Problems with the fragile, easily fractured or damaged powdered infiltrant are eliminated, cutting the scrap rate to zero.

In addition to the processing issues described above the new wrought copper infiltrant eliminates the need for a separate set of tools to press the infiltrant as well as the press to compact the infiltrant and the personnel to monitor and handle the fragile powdered infiltrant. Storage and transport of these delicate compacted infiltrant performs is also removed from the processing route, replaced by a robust, rigid, easily handled wrought wire infiltrant.

## MECHANICAL PROPERTIES

The initial investigations of the wrought wire infiltrant focused on the widely used FX-1008 copper infiltrated plain carbon steel alloy, consisting of a iron powder with 0.8% combined carbon and infiltrated with 8-14.9% copper. The effect of % copper infiltrated, skeletal density and type of iron powder used to produce the preform were studied [5]. The second investigation focused on the potential for copper infiltration to be used to boost the sinter hardening response of low alloy steels. In this study both the composition of the prealloyed steel powder and amount of graphite addition were varied while the sintering procedure and amount of wrought wire infiltrant were held constant [6]. The results of these two investigations are presented in the following two sections.

**FX-1008 RESULTS** - The results of the first investigation for the FX-1008 system are listed in Table 1 and reflect the use of an F-0008 base iron matrix using QMP Atomet 28 iron powder and the wrought wire infiltrant. Standard values taken from MPIF Standard 35 for the FX-1008 grade are included in Table 1 for comparison to the test results.

The test results find the new infiltrant to be very effective in strengthening the iron matrix using both a medium and high density iron matrix. The higher matrix density results demonstrate the benefit of using a higher density matrix for increased strength and hardness. No improvement in ductility or impact resistance was noted at this higher matrix density. Both results far exceeded the strength values listed in MPIF Standard 35 for the FX-1008 grade with the lower density matrix results 30% higher than the values listed in Standard 35 and the higher density matrix 50% stronger.

The results of the second investigation for the FX-1008 system are listed in Table 2 and now reflect the change in the base iron powder to QMP Atomet 1001 water atomized steel powder infiltrated with the wrought wire infiltrant and a commercial powdered infiltrant. Standard values from MPIF Standard 35 for the FX-1008 grade are included in Table 2 for comparison to the test results.

The test results find the wire infiltrant just as effective in strengthening the steel matrix as the commercial powdered infiltrant, using 17% less infiltrant. Both infiltrant results far exceeded the transverse rupture strength values listed in MPIF Standard 35 for the FX-1008 grade. The infiltrated hardness values were comparable for the two infiltrants and the standard value.

The results of the third investigation for the FX-1008 system are listed in Table 3 reflect the F-0008 base iron matrix again using QMP Atomet 28 iron powder, the wire infiltrant and a second commercial powdered infiltrant #2. Standard values for the FX-1008 grade are included in Table 3 for comparison to the test results.

Table 1 – FX-1008 Using Wire Infiltrant and QMP Atomet 28 Iron Matrix

| Green Density<br>g/cm <sup>3</sup> | % Infiltrant | Infiltrated Density<br>g/cm <sup>3</sup> | Tensile Strength<br>MPa (psi) | Yield Strength<br>MPa (psi) | Elongation % | TRS<br>MPa (psi)  | Hardness | Impact Energy<br>(J) (ft-lbs) |
|------------------------------------|--------------|------------------------------------------|-------------------------------|-----------------------------|--------------|-------------------|----------|-------------------------------|
| 6.65                               | 14.5         | 7.55                                     | 790<br>(114,000)              | 590<br>(86,000)             | 2.7          | 1480<br>(215,000) | 21 HRC   | 15<br>(11)                    |
| 6.90                               | 13.5         | 7.70                                     | 880<br>(127,000)              | 650<br>(94,000)             | 3.0          | 1510<br>(219,000) | 27 HRC   | 16<br>(12)                    |
| MPIF Std 35<br>FX-1008-50          |              | 7.3                                      | 600<br>(87,000)               | 410<br>(60,000)             | 3.0          | 1140<br>(166,000) | 89 HRB   | 14<br>(10)                    |

Table 2 – FX-1008 Using Wire Infiltrant and QMP Atomet 1001 Steel Matrix

| Infiltrant                | Green Density<br>g/cm <sup>3</sup> | % Infiltrant | Infiltrated Density<br>g/cm <sup>3</sup> | TRS<br>MPa (psi)  | Hardness<br>HRB | Dimensional Change % |
|---------------------------|------------------------------------|--------------|------------------------------------------|-------------------|-----------------|----------------------|
| Wire                      | 6.7                                | 11.3         | 7.33                                     | 1530<br>(222,000) | 94              | +0.58                |
| Powdered #1               | 6.7                                | 13.6         | 7.38                                     | 1450<br>(210,000) | 90              | +0.66                |
| MPIF Std 35<br>FX-1008-50 |                                    |              | 7.3                                      | 1140<br>(166,000) | 89              |                      |

Table 3 – FX-1008 Using Wire Infiltrant, Powdered Infiltrant #2 and QMP Atomet 28 Iron Matrix

| Green Density<br>g/cm <sup>3</sup> | % Infiltrant   | Infiltrated Density<br>g/cm <sup>3</sup> | Tensile Strength<br>MPa (psi) | Yield Strength<br>MPa (psi) | Elongation % | TRS<br>MPa (psi)  | Hardness | Impact Energy<br>(J) (ft-lbs) |
|------------------------------------|----------------|------------------------------------------|-------------------------------|-----------------------------|--------------|-------------------|----------|-------------------------------|
| 6.7                                | 10.9           | 7.45                                     | 790<br>(114,000)              | 630<br>(91,000)             | 2.0          | 1290<br>(187,000) | 92HRB    | 20<br>(14)                    |
| 6.7                                | 14.0           | 7.60                                     | 830<br>(120,000)              | 630<br>(91,000)             | 1.3          | 1340<br>(195,000) | 28 HRC   | 15<br>(11)                    |
| 6.95                               | 10.8           | 7.65                                     | 850<br>(123,000)              | 660<br>(96,000)             | 1.3          | 1430<br>(207,000) | 28 HRC   | 18<br>(13)                    |
| 6.95                               | 14.3           | 7.80                                     | 850<br>(123,000)              | 680<br>(98,000)             | 1.2          | 1490<br>(216,000) | 32 HRC   | 15<br>(11)                    |
| 6.7                                | Powder<br>13.5 | 7.45                                     | 810<br>(117,000)              | 620<br>(90,000)             | 1.0          | 1300<br>(189,000) | 25 HRC   | 16<br>(12)                    |
| MPIF Std 35<br>FX-1008-50          |                | 7.3                                      | 600<br>(87,000)               | 410<br>(60,000)             | 3.0          | 1140<br>(166,000) | 89 HRB   | 14<br>(10)                    |

The test results find the wrought wire infiltrant to be very effective in strengthening the iron matrix using both a medium and high density iron matrix, and using a medium and high level of infiltrant within the FX-1008 composition range. The medium density matrix using the 10.9% wire infiltrant provided mechanical properties equivalent to the powdered infiltrant #2 at 13.5% infiltrant and 30% stronger than the values listed in MPIF

Standard 35. Increasing the amount of wire infiltrant from 10.9% to 14.0% increased the infiltrated density to  $7.6 \text{ g/cm}^3$  but had limited effect on strength, ductility or impact resistance when using the  $6.7 \text{ g/cm}^3$  matrix density. Increasing the matrix density from  $6.7 \text{ g/cm}^3$  to the high density matrix of  $6.95 \text{ g/cm}^3$  further increased the infiltrated density but again had no significant effect in raising strength or hardness or impact resistance.

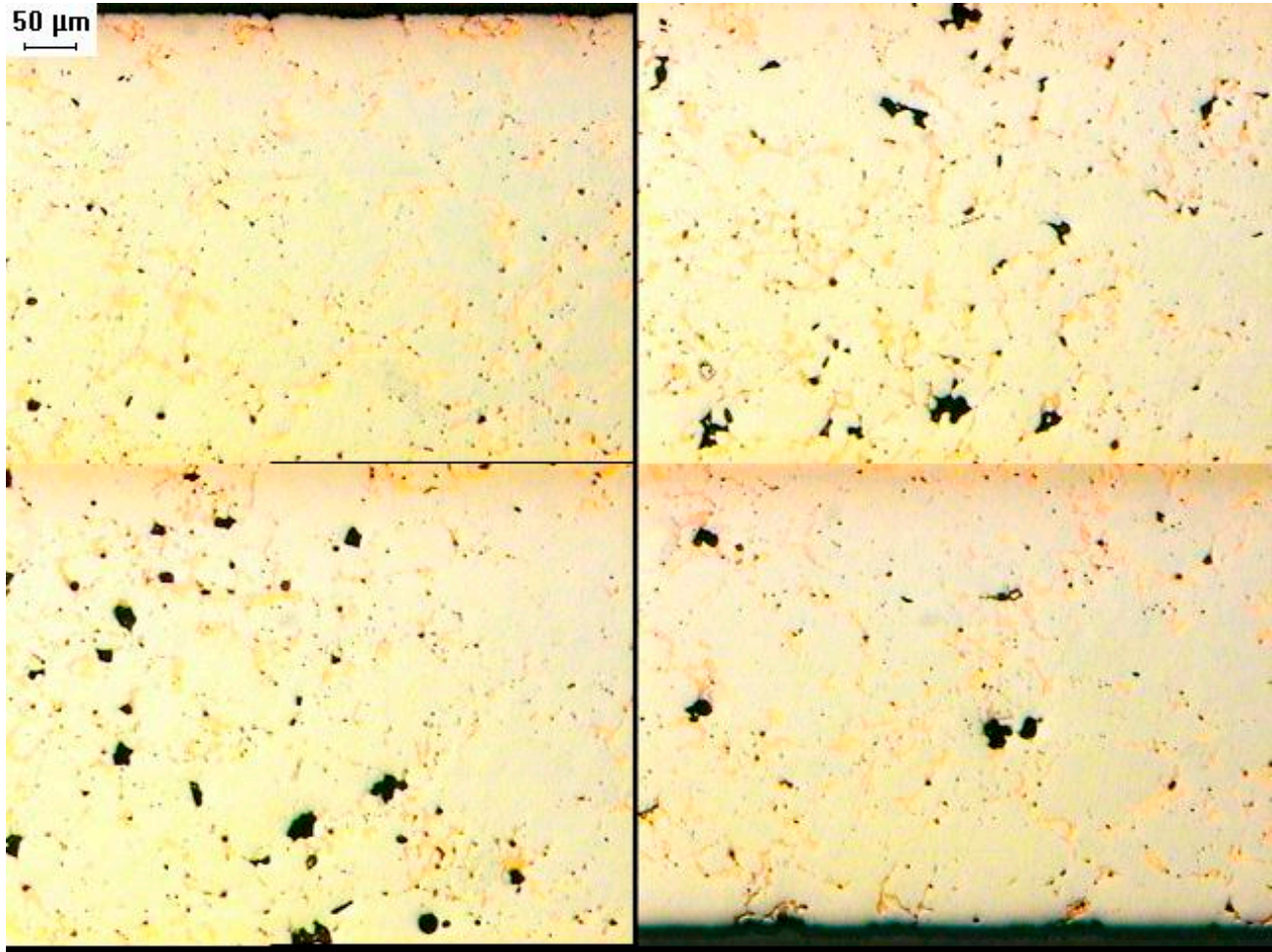


Figure 1. Photomicrographs illustrate the unetched structure of the  $6.90 \text{ g/cm}^3$  density matrix with an infiltrated density of  $7.8 \text{ g/cm}^3$ . The upper left view is the top surface (infiltrant placement surface), the lower left view about one-third through the part thickness, the upper right view about two-thirds through the part thickness and the lower right view the bottom of the specimen.