1st TMS/ABM International Materials Congress TMS CO-ORGANIZADOR
ANAIS PROCEEDINGS ISSN 1516-392X

# PROCESS AND CHARACTERIZATION OF DUAL PHASE STEEL FOAM[1]

Andrea Gruttadauria[2]
Davide Mombelli[3]
Enrique M. Castrodeza[4]
Carlo Mapelli[5]

**Summary**

Porous materials featuring cellular structures are known to have many interesting combinations of physical and mechanical properties. Some of them have been extensively used in the transportation field (i.e. balsa wood). Steel foams presented promising theoretical properties for both functional and structural applications in transportation, but processing of such a kind of foams is complex due to their high melting point. Recently a technique for processing Cu-based alloys open-cell foams through the molten metal infiltration of a leachable bed of amorphous $SiO_2$ particles was proposed. A variation of the proposed technique that uses SiC particles as space holder is now presented and was recently successfully applied for dual phase steel foam processing. Results from a processing of dual phase DP500 steel foams, including some morphological, micro-structural and mechanical characterization, are here presented.

**Keywords:** dual phase steel, cellular metals, metal foams, silicon carbide

---

[1] 1st TSM-ABM International Material Congress. July 26-30, 2010, Rio de Janeiro, RJ, Brazil
[2] Ph.D., Dipartimento di Meccanica, Politécnico di Milano. Via G. La Masa 34, 20156 Milano, MI, Italia.
[3] Eng., Dipartimento di Meccanica, Politécnico di Milano. Via G. La Masa 34, 20156 Milano, MI, Italia.
[4] D.Sc., Departamento de Eng. Metalúrgica e de Materiais, COPPE-UFRJ, CP 68505, 21941-972 Rio de Janeiro, RJ, Brasil.
[5] D.Sc., Dipartimento di Meccanica, Politécnico di Milano, Via G. La Masa 34, 20156 Milano, MI, Italia.

## 1. Introduction

Based on their particular morphology cellular metals and alloys offers an interesting mix of physical-chemical and mechanical properties. That makes these materials very attractive both for structural and functional applications. Cellular metals are now produced by several processes, including molten metal infiltration of a leachable bed of solid particles, also known as space holder. A recent work introduced the use of amorphous $SiO_2$ (silica-gel) beads as space holder for open-cell Cu-based foam processing through molten metal infiltration. Once infiltrated, $SiO_2$ particles are dissolved by a wet solution of hydrofluoric acid (HF). Unfortunately this technique is not applicable for processing of steel foams, mainly due to the high melting point of steels (~1500 ℃). For overcoming this limitation it is proposed to use beta-SiC as space holder. SiC can withstand the infiltration efforts till 1800 ℃ without problems and can be also dissolved by aqueous HF. On the other hand, the chemical stability of SiC at such temperatures diminishes the possibility of interaction between the molten metal and the space holder. Following this route highly homogeneous dual-phase steel foams featuring opened cell structure were processed. The proposed methodology is based on cheap commercial consumables and simple technology, focusing on low cost foams with interesting cost/benefit ratios. Based on the acquired scientific literature the proposed route represents the first attempt for applying SiC as space holder for steel foam processing.

Open-celled metal foams typically show low density, high surface vs. volume ratio, low stiffness and permeability to fluid flow and so they represent a suitable opportunity for the production of several components, i.e. elements to be inserted in sandwich systems, vibration damping components, filters, substrates for catalytic reactions, electrodes, porous media for biomedical applications, heat exchanging elements etc. Dual phase steels are much used in the automotive field, for example in seats, bumpers and in reinforced shells. So the dual phase steel foam can found application in this field because of morphology and material properties.

## 2. Experimental

### *2.1. Space holder*

During the foam processing the space holder was commercial Beta-SiC Vukopor S® in the form of foundry filters. Through EDS examination it was possible to observe that they are composed by approximately 90% in SiC and the other 10% in alumina and silica. The filters were available in three different porosity, i.e. 10, 20, and 30 pore per inch (ppi), as shown in figure 1. Beta-SiC is virtually inert and has no known adverse and detrimental effects on the environment. The filters are normally used as foundry filters and is commercially available worldwide.

### *2.2. Wet chemical etching of Beta-SiC*

Beta-SiC was dissolved by wet chemical etching in an aqueous solution of HF (25% vol.). In the literature it is possible to find several reactions for HF etching of SiC. The stechiometric reaction is defined as (V. Villavecchia, G. Eigenmann, 1996. Nuovo dizionario di merceologia e chimica applicata, volume 6):

$SiC_{(s)} + 4HF_{(aq)} \rightarrow SiF_{4(g)} + 2H_2O + C_{(S)} \quad T_{amb}$ (1)

The highly porous morphology of Beta-SiC filters allows improving the dissolution kinetics by aqueous HF. According to our experience, stirring of HF solution also improves the dissolution velocity.

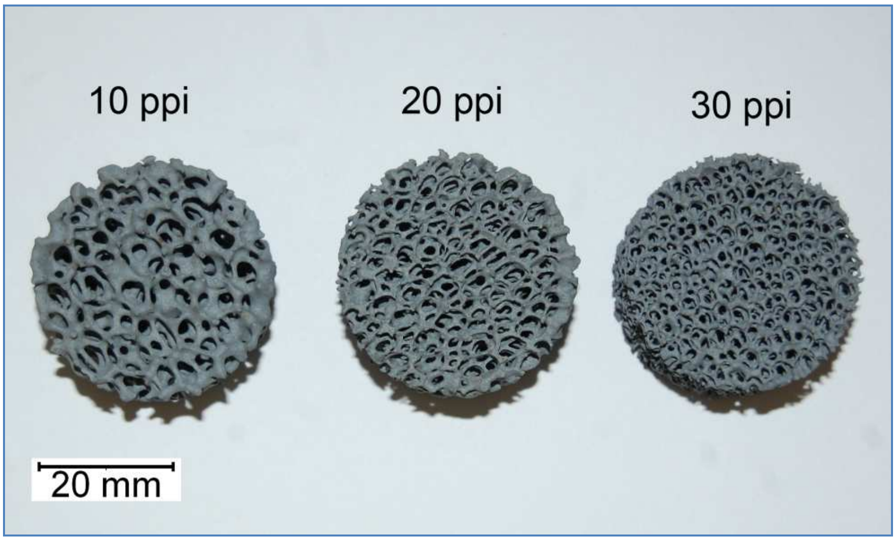



**Figure 1**. Beta-SiC filters having different porosity.

### 2.3. DP500 steel

*Dual phase steel* (DP) are high strength steels having a biphasic structure composed by a (soft) ferritic matrix which contains an uniform dispersion of (hard) martensitic phase. Ferrite gives to the material a good ductility while martensite ensures good mechanical properties. The mechanical properties of this kind of steel increased with the increasing in martensitic fraction. The total amount of martensite in the alloy depends on the carbon content and on the thermomechanical treatment. The chemical compositions of the processed alloys, obtained by X-ray analysis, are shown in table 1.

Some typical properties of commercial DP500 steel are shown in Table 2, which are completely consistent with the values featuring the alloys applied in the experiments.

**Table 1**. Chemical composition of DP500 steel.

ISSN 1516-392X

| DC500DP | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Component | Fe | C | Si | Mn | P | S | N | Cr | Ti | Ni | Cu |
| Weight % | 98,2 | 0,0595 | 0,3082 | 1,205 | 0,0073 | <0,0050 | 0,0118 | 0,0274 | 0,0022 | 0,0348 | 0,0136 |
| Component | V | Sn | Nb | As | Zr | W | Co | Pb | Mo | Al | |
| Weight % | 0,009 | 0,0569 | 0,0569 | 0,0018 | <0,001 | <0,0100 | 0,0046 | <0,001 | <0,001 | 0,2257 | |

**Table 2**. Typical properties of commercial DP500 at room temperature (W. Nicodemi, 2004. Acciai e leghe non ferrose)

| | |
|---|---|
| Density | ~ 7,85 g/cc |
| Melting Point | ~ 1530 ℃ |
| Young Modulus | ~ 210 GPa |
| Tensile Strength, Ultimate | 570 - 710 MPa |
| Tensile Strenght, Yeld | 500 - 620 |
| Elongation at Break | 12 % |
| Hardness, Brinel | > 45 |

### *2.3.1 Determination of the critical points $A_{C1}$ and $A_{C3}$ for quenching*

The biphasic structure of this kind of steels is obtained through intercritical quenching. During this thermal treatment the specimens are subjected to a temperature defined by the critical points $A_{C1}$ and $A_{C3}$, and then water cooled. The temperature $A_{C1}$ is the eutectoid temperature while $A_{C3}$ is defined as the temperature in which the α-γ phase transformation of the steel starts. These points depend on the chemical composition of the alloy and were evaluated through a DSC analysis. The report of this analysis is shown in diagram 1. From the DSC report it is clearly seen that for the analyzed alloy $A_{C1} \cong 741$ °C and $A_{C3} \cong 898$ °C. As a consequence, the temperatures chosen for the beginning of fast cooling were 770 ℃, 800 ℃, and 830 ℃.

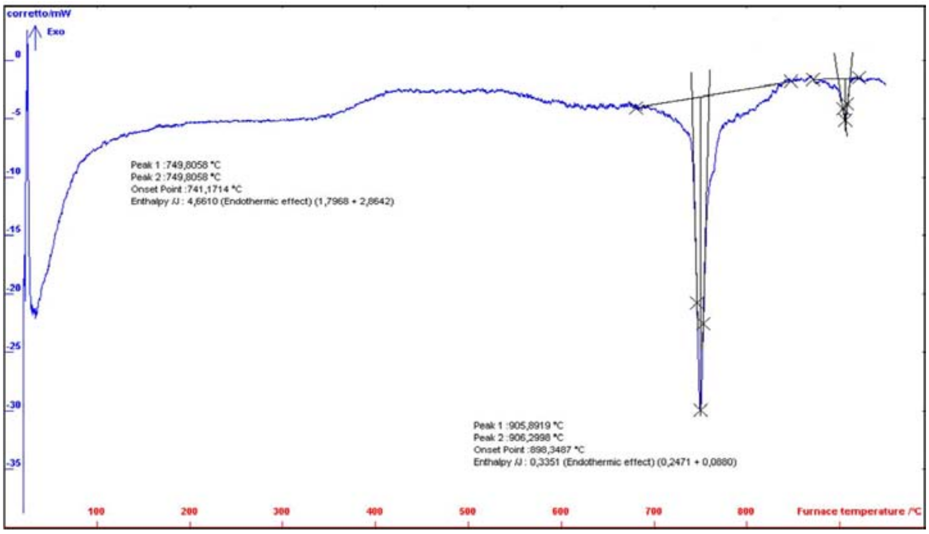



**Diagram 1**. DSC report from DP500 alloy analysis.

*2.4. Foam preparation*

The infiltration process was performed in a 10 kW centrifugal induction casting machine having a cylindrical alumina crucible. The infiltration temperature was controlled by a thermocouple placed into the molten metal. The SiC filters as space holder were placed into a graphite mold. Before reaching approximately 100 °C above the melting temperature in the molten metal, the thermocouple was withdrawn, the induction main power is switched off, and the centrifuge is switched on. At this point the molten metal was forced into the mold by the centrifugal force, infiltrating into the space holder. After complete solidification and cooling the obtained solid (steel and space holder) was submerged in an aqueous HF bath (25% vol.) till complete SiC dissolution. The three processed foams having different porosities are shown in figure 2.

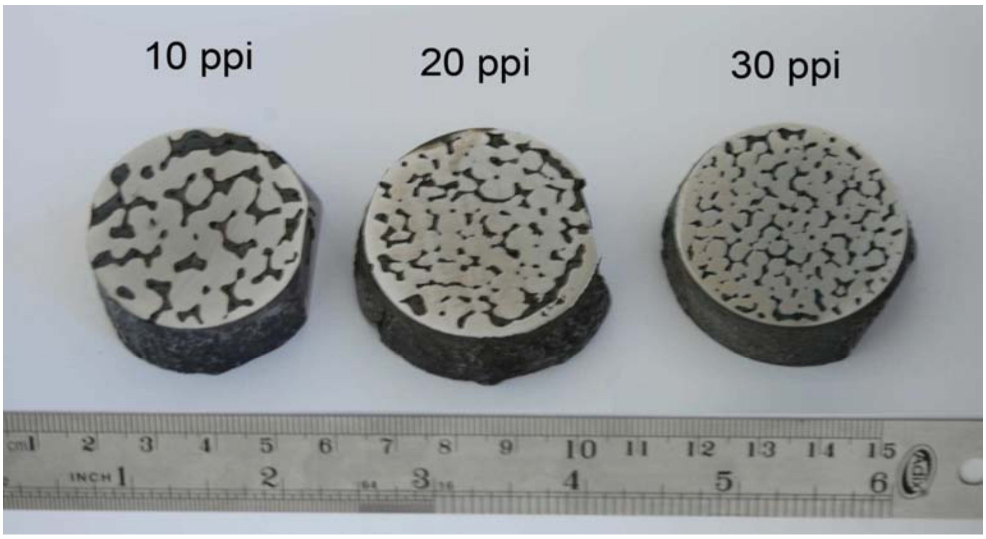



**Figure 2**. Dual phase steel foams having different porosity.

*2.5. Relative density calculation*

The relative density of the final foam, that is the foam density to bulk density ratio, was calculated based on measurements of physical dimensions of the final (post-machined) cellular solid and on weight measurements. The same calculation could be also done through quantitative metallography by image processing. In this case some images were taken from the steel foam surfaces (figure 3) and were then analyzed through ImageProPlus software. The results from these two techniques were then compared. It is interesting to note that through the image analysis technique it is also possible to calculate the surface to volume ratio, or specific surface density. Results of both calculations are shown in table 3.

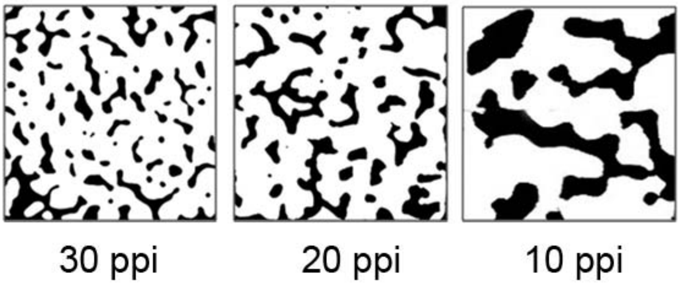



**Figure 3**. Reworking of the foams image to calculate density and surface-volume ratio.

**Table 3**. Density and surface-volume ratio.

| Porosity | Relative density (image processing) | Relative density (geometrical) | S/V [1/m] (image processing) |
|---|---|---|---|
| 30 ppi | 0,65 | 0,65 | 770 |
| 20 ppi | 0,66 | 0,65 | 705 |
| 10 ppi | 0,64 | 0,65 | 455 |

*2.6. Microstructure*

For microstructural analysis the samples were polished and immersed in Nital (5%) to reveal the boundary grains, and in Sodium Metabisulfite to reveal the martensitic islands. Micrographs from different quenched specimens showing different amounts of martensite were taken, similar to the presented in figure 5.

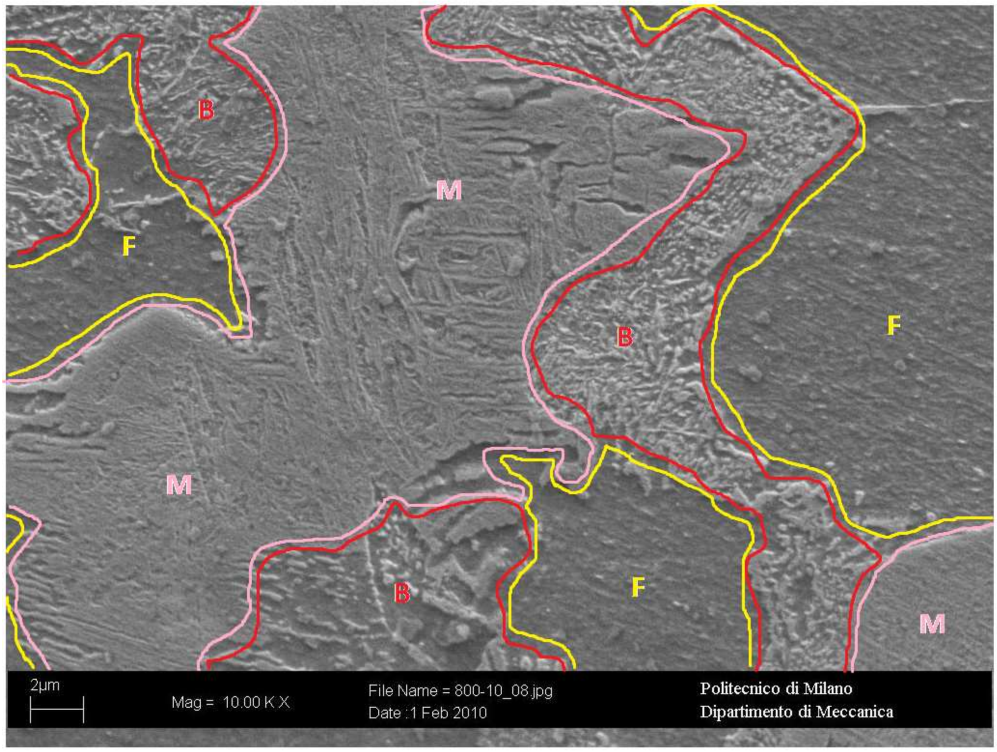
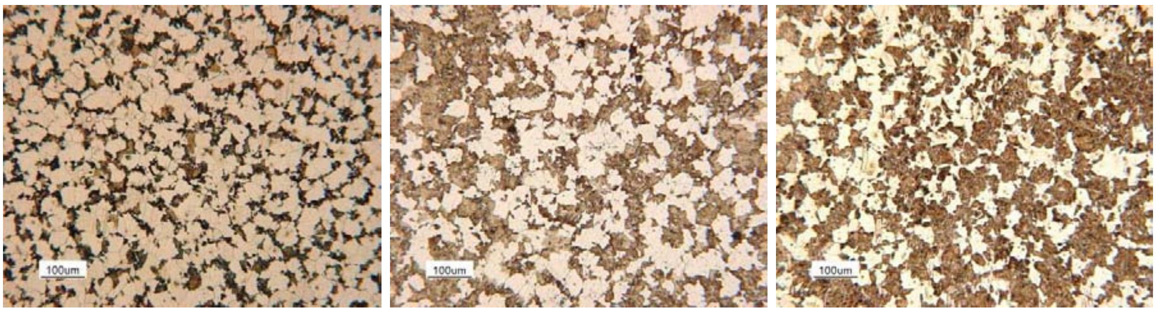



**Figure 4**. DP500 microstructure. Quenching temperature = 800 ℃.

In figure 4 it is possible to see the alloy micro-structure after thermal treatment. The structural components are martensite (M), ferrite (F) and bainite (B). This kind of structure is predicted by Bain's curves (W. Nicodemi, 2004. Metallurgia, principi generali).



(a) (b) (c)

**Figure 5**. DP500 microstructures. Quenching temperature: (a) = 770 ℃, (b) = 800 ℃, and (c) = 830℃.

From figure 5 it is possible to see the different amount of martensite due to different thermal treatments.

*2.7. Compression testing*

A basic mechanical characterization of the DP500 foams was performed through uniaxial compression testing on prismatic specimens (12 by 12 mm in cross section and 18 mm in height). The specimens were tested in an electro-mechanical universal testing machine under constant crosshead velocity (1 mm/min) under displacement control. For the Young's modulus evaluation some unloading-reloading cycles were performed during the tests. Figure 6 shows results from the three different space holders and quenching temperature = 830 °C.

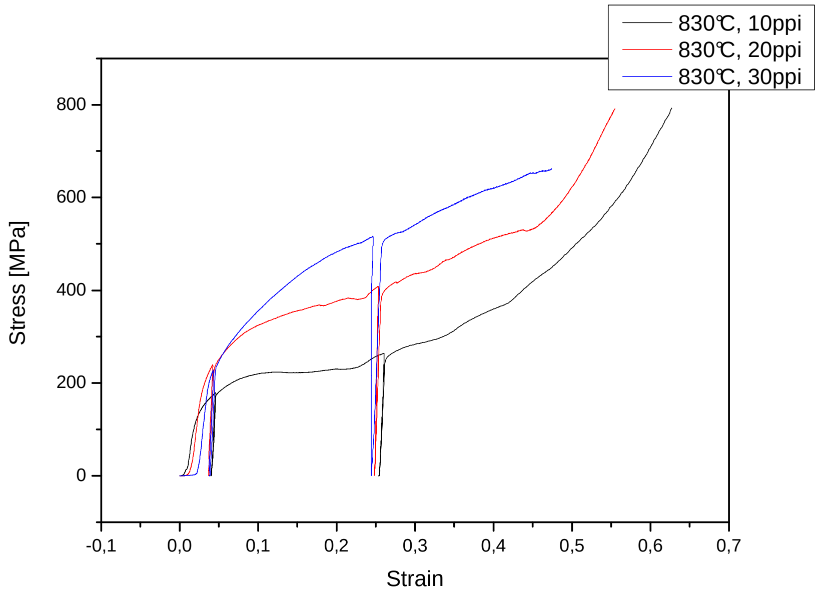



**Figure 6**. Strain-stress records from DP500 foam compression testing.

As can be seen all the specimens showed typical cellular metal stress-strain behavior. The records are comparable to results from metallic foams having similar relative densities (Gaillard et al., 2004; Pollien et al., 2005). In all the cases the elastic modulus measured from the unloading-reloading cycle was close to 50 GPa, which is in the expected range according to theoretical models in literature (Ashby et al., 2000). Comparing the curves from Figure 6 and the results of relative density calculations from Table 3 it is also possible to see that, even for steel foams having the same relative density, the increasing on the porosity of the filters used as space holders promoted and increasing in the mechanical resistance of the foam. Based on the literature and from the point of view of the relative density this behavior is not expected and need to be further investigated.

## 3. Conclusions

Based on the experimental results it is possible to conclude:

1. The production of open-celled metal foams of DP500 steel by molten metal infiltration of SiC filters then leached by aqueous HF has been experimentally demonstrated.
2. The space holder (Beta-SiC filters) remained stable in shape and dimensions during liquid steel infiltration (processing temperature ~ 1650 ℃). Because of the

high chemical stability of SiC no interaction with the metallic system during liquid infiltration has been found.

3. The resulting metal foams had a relative density of 0.65 and all the observed cells are open and interconnected.
4. The compression tests demonstrate that the steel foam specimens show the typical stress-strain behavior of cellular metals.
5. Different degrees of porosity of the SiC filters used as space holders permitted to obtain different mechanical properties and different surface-volume ratio, even with the same final relative density.

## References

Ashby M.F., Evans A., Fleck N.A., Gibson L., Hutchinson J.W., Wadley H., 2000. Metal foams: a design guide, Butterworth-Heinemann, Boston.

Banhart J., 2001. Manufacture, characterisation and application of cellular metals and metal foams, Progr. Mat. Sci. 46, 559-632.

Castrodeza E.M., Mapelli C. Processing of brass open-cell foam by silica-gel beads replication (2009) Journal of Materials Processing Technology, 209 (11), pp. 4958-4962.

A. Verdooren, H. M. Chan, J. L. Grenestedt, m. P. Harmer, h. S. Caram, 2005. Fabrication of ferrous metallic foams by eduction of ceramic foam precursors, Journal of materials science 40 (2005) 4333 – 4339.

Lermontov S.A.,Malkova A.N., 2007. A new method for dissolution of silica gel in a pentafluoropropionyl fluoride-tertiary amine system, Russian Chem. Bull. 56, 435-437.

Pollien A., Conde Y., Pambaguian L., Mortensen a., 2005. Graded open-cell aluminum foam core sandwich beams, Mat. Sci. Engng. A 404, 9-18.

Spierings G., 1993. Wet chemical etching of silicate glasses in hydrofluoric acid based solutions, J. Mat. Sci. 28, 6261-6273.

W. Nicodemi, 2004. Metallurgia, principi generali, Zanichelli

W. Nicodemi, 2004. Acciai e leghe non ferrose, Zanichelli

Wadley H.N.G., 2002. Cellular metals manufacturing, Adv. Engng. Mat. 4, 726-733.

V. Villavecchia, G. Eigenmann, 1996. Nuovo dizionario di merceologia e chimica applicata, volume 6. Hoepli.