



Comparative Analysis of Characteristics of Stainless Steel Cellular Material Prepared Through Powder Metallurgy using Accicular and Crushed Urea as Spaceholder

SHAILENDRA JOSHI

Department of Mechanical Engineering, NPSEI, Pithoragarh, Uttarakhand, India.

Abstract

Stainless steel has an excellent mechanical properties as well as high corrosion resistance. Stainless steel foams therefore seemed as an attractive material for impact energy absorption applications where damping capability is required such as in vehicles and buildings. Also when stainless steel foam is produced as stainless steel foam, the material density will be reduced thus the resulting foam will be a combination of light weight and high strength that can also be used in high strength applications. In our analysis we tried to produce stainless steel foam through powder metallurgy in order to control mechanical properties in a better manner compared to casting method. Also we try to compare the pore morphology in foams on changing the space holder from accicular urea to crushed urea using FE-SEM. The properties of stainless steel foam, to a large extent are found to depend on the pores arrangement which is decided by the space holder utilized during its synthesis using powder metallurgy route. The stainless steel obtained using accicular carbamide as space holder are found to possess accicular or irregular pores whereas those produced with crushed urea as space holder possesses nearly circular holes. Also the previous foams are found to have better mechanical properties contributing towards more useful metallic foam.



Article History

Received: 16 October 2018

Accepted: 27 May 2019

Keywords:

Accicular;
Arrangement;
Crushed;
Damping;
Foams.

Introduction

Metal foams are cavitated structures occupied by solid metal with gas-filled pores acquiring a large volume. They have various unique properties simultaneously

such as low density (greater porosity), high compression strength, higher stiffness, more energy absorption property & low thermal conductivity which make it desirable for structural & functional

CONTACT Shailendra Joshi ✉ shailme09@gmail.com 📍 Department of Mechanical Engineering, NPSEI, Pithoragarh, Uttarakhand, India.



© 2019 The Author(s). Published by Oriental Scientific Publishing Company

This is an Open Access article licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License
Doi: <http://dx.doi.org/10.13005/msri/160211>

applications.¹ The commonly used metal foams are made up of aluminium, titanium, tantalum and steel. The microstructure of metal foams consists of a complex combination of solid and void phases.² The voids have random shape & size and mostly don't follow any pattern. Therefore randomness, which is obviously introduced into metal foams during manufacturing processes, is creating more uncertainty in the behavior of metal foams compared to solid steel. Therefore, studying the cause and control of uncertainty in the structures of metal foams is more beneficial since they will be cause the variation in their properties.

Various methods exists for the manufacture of stainless steel foams such as melt-gas injection, powder metallurgy, investment casting, melt-foaming and melt infiltration.³⁻⁵ Since powder metallurgy is cost effective and flexible it has been considered a suitable method for stainless steel foam fabrication.⁶⁻⁷ Also it results in better uniform distribution of pores in foams, more precise control of process

variables and pore size⁸ & high relative density. Steel foam is a material that can create materials with a variety of different morphologies that have desirable mechanical properties. Metal foams have an extended stress plateau in their compressive stress-strain curves, which is effective for absorbing energy at a constant stress level.

Metal foams are affective in automotive, railway, aerospace and chemical applications, where low weight, reduced chemical pollution and high degree of comfort and safety are needed⁹

Experimental Work

Measurement

In order to obtain porosity 40, 50 & 60% in the resulting structure, the stainless steel -316L powder and acccicular urea are individually packed in different packets in required quantity after measurement in electronic weighing machine. Now corresponding to 40 % porosity, the contents of packets of ss and acccicular urea powder are placed inside crucible for nearly 14 minutes. Repeating the

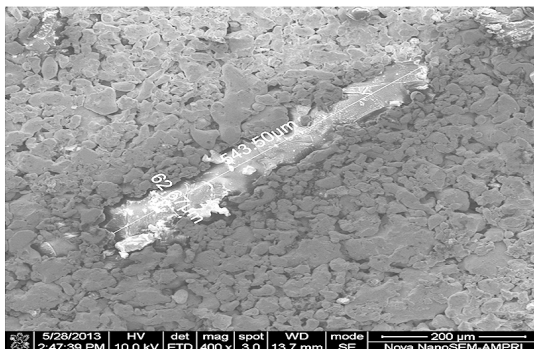


Fig. 1: Microstructure showing acicular carbamide particle in the green compact

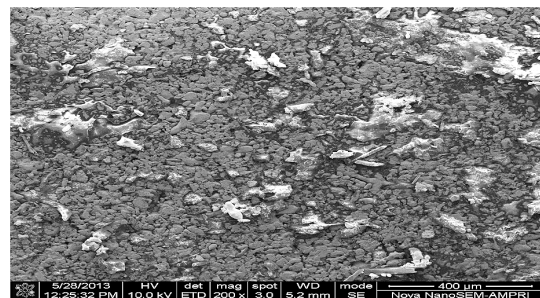


Fig. 2: Microstructure of crushed carbamide particles in the green compact

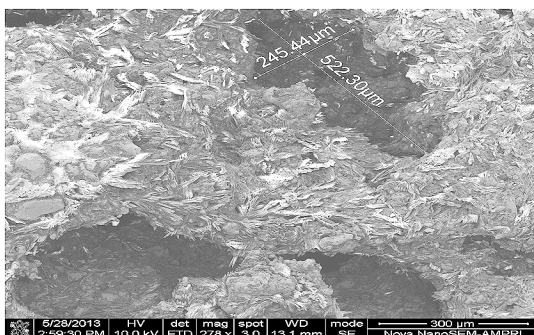


Fig. 3: Micrograph showing preheated sample (using acicular urea space holder)

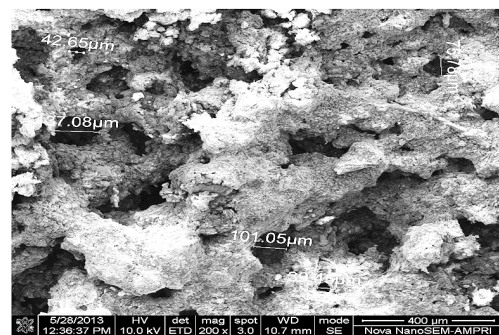


Fig. 4: Micrograph showing preheated sample (using crushed urea space holder)

same for 50 and 60% porosity packets. In similar manner the samples of crushed urea particles are prepared maintaining porosity 40, 50 & 60 %.

Mixing and Preheating

These properly mixed powders in appropriate amount are placed inside a cylindrical die of 10 mm

diameter and are subjected to a pressure of 250 MPa for 30 seconds producing green compacts of cylindrical shape complementary to die inner portion. After that, the green compact samples of low strength are preheated in a cylindrical furnace at 350 °C, for nearly two and half hour.



Fig. 5: Sintered stainless steel foam samples with varying porosity processed using acicular crystals of urea

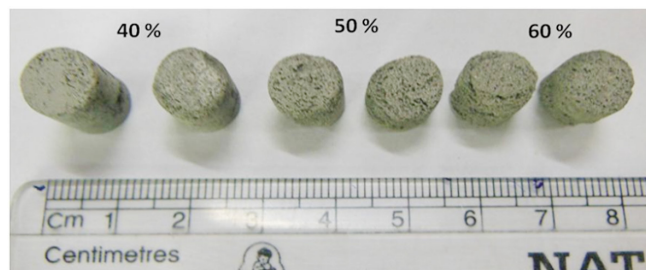


Fig. 6: Sintered Stainless steel foam samples with varying porosity processed using fine urea particles

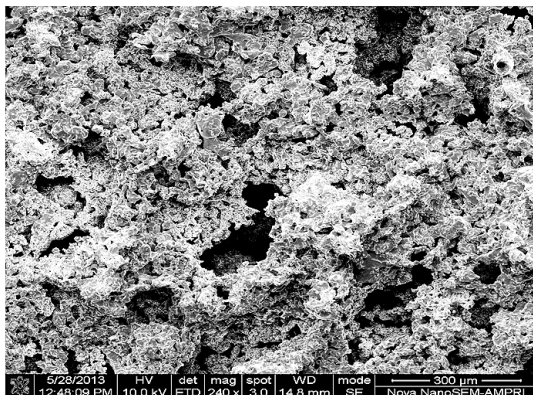


Fig. 7: SEM image showing sintered foam sample (using acicular urea space holder)

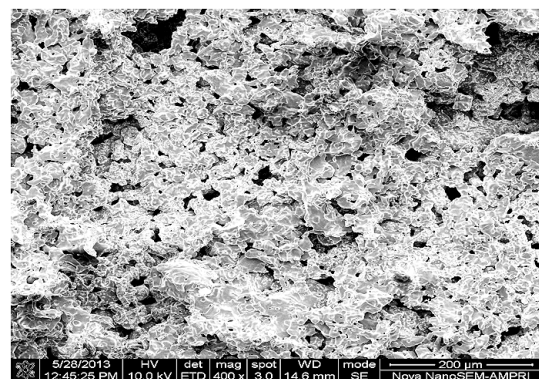


Fig. 8: SEM image showing sintered sample (using crushed urea space holder)

Sintering

The preheated samples are heated up to 1110 °C and kept at the same temperature for about 115 minutes. Heating rate maintained during sintering is 12 °C/min. For preventing any residual stresses and structural deformation, the samples are remained in the furnace for a time period of 65 min. As a result the samples volume attains a uniform temperature of 1100 °C. Afterwards these specimens are kept in the furnace for cooling.

The microstructure arrangements of both types of distinct ss foam samples obtained using accicular

and crushed carbamide are viewed on a Scanning Electron Microscope.

The mechanical properties of the samples are characterized after performing compression test on the specimen on Instron universal testing machine at the strain rate of 10-3 s-1.

Results and Discussion

Green compact samples compacted surface are analyzed on FE-SEM The microstructure shows the position of urea particles in the stainless steel matrix in the figure. In the image the black area

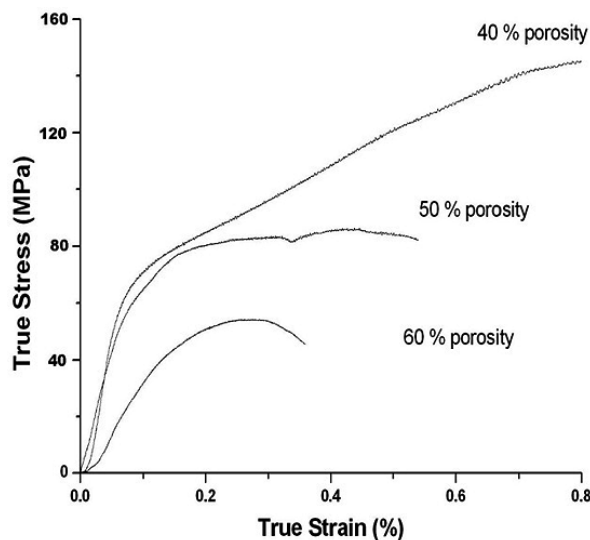


Fig. 9: True stress versus True strain curve (for acicular urea sample)

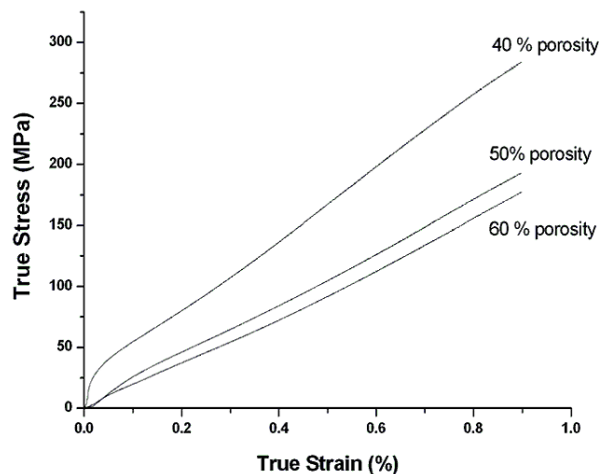


Fig. 10: True stress vs True strain curve (for crushed urea sample)

shows stainless steel particles whereas white regions represent the urea particles in the matrix. We can observe from the SEM images that larger sized pores results in case of green stainless steel compacts containing accicular urea whereas small size uniformly distributed pores in case of that containing crushed urea particles. This occurs due to variation in the size of urea particles and contributing mixing in crucible.

Due to the evaporation of urea particles, whether accicular or crushed, during preheating of green compact samples the pores gets produced. The pores obtained are larger in case of samples resulted from accicular urea than that of crushed urea particles due to deformation and distortions resulted by increase in temperature and evaporation. Pores dimension are more compared to the size of urea particles since urea particles vaporise after destroying the mechanical bonds that created high dimension voids.

After preheating both types of samples are sintered to give strength and produce metallurgical bonds in the stainless steel foam samples. The preheated part is heated at a temperature greater than the preheating temperature but below the melting point of matrix.

The samples with higher percentage of urea are irregular in shape because after preheating of green compacts, the samples with higher percentage of urea have higher porosity making the pre-heated compact much weaker. Due to less bonding strength the samples having higher percentage of urea did not sustain its shape after pre-heating. The irregularity in shape is more in case of samples obtained through accicular urea particles than that obtained from crushed ones but the strength is increased after sintering. The pores resulted beyond sintering are less in dimensions than those of the pores produced after preheating due to the large restoring force producing more pore shrinkage during sintering.

The pores obtained in case of sintered foams while utilizing accicular urea as space holder are accicular whereas in samples containing crushed carbamide

as space holder are nearly about circular in shape. This is due to the shape of space holder particles and metallurgical bonding in stainless steel matrix during sintering.

During the compression test of stainless steel foam samples of 40, 50 & 60% porosity. In case of ss foam samples comprising of accicular urea as spaceholder the plateau region is obtained when the porosity reaches 50 vol % & beyond it whereas it is not distinct in case of samples obtained from crushed urea as spaceholder due to large size accicular pores obtained in previous case. They have high energy absorption capacity. The foam samples yield strength lowers with the increase in porosity in later case. Also the material is ductile and can be used in lightweight structural applications.

Conclusion

Thus stainless steel foams could be successfully processed through powder metallurgy and urea can be efficiently used as a space holder. Also the amount of porosity and material density is directly proportional to the amount of space holder used. The pores dimensions produced depends on the nature of space holder utilized, sintering temperature and time interval of preheating & sintering.

The foams containing larger dimensions pores showed distinct plateau regions at 50 and 60 vol. % porosity corresponding to a plateau stress of 80 and 55 MPa whereas those possessing circular pores doesn't possess distinct plateau region. The processed accicular foams having distinct plateau regions shows their impact energy absorption characteristics & those processed with crushed urea as a space holder can be utilized in high strength structural applications.

Acknowledgments

The author thanks MANIT, Bhopal & CSIR-AMPRI, Bhopal for providing support during the study and research.

Conflicts of Interest

The authors have no conflicts of interest to disclose.

References

1. V.C. Srivastava, K.L. Sahoo, "Processing, stabilization and applications of metallic foams. Art of science", *Materials Science Poland*, Vol. 25, No. 3, March 2007.
2. N. Babcsán, J. Banhart, D. Leitmeyer, "Metal Foams – Manufacture And Physics Of Foaming", International Conference, "advanced Metallic Materials" 5 – 7 November 2003.
3. Porous and cellular materials for structural applications. In: Schwartz DS, Shih DS, Evans AG, Wadley HNG, editors. *MRS Symp. Proc.*, vol. 521, 1998.
4. Mechanical properties of porous and cellular materials. In: Sieradzki K, Green DJ, Gibson LJ, editors. *MRS Symp. Proc.*, vol. 207, 1990.
5. John Banhart, "Manufacture, characterisation and application of cellular metals and metal foams", *Progress in Materials Science*, January 2000, pp 559–632.
6. J. Banhart, J. Baumeister, "Deformation characteristics of metal foams", *Journal of Material Science* 33, 1998, pp 1431-1440.
7. Niu Wenjuan, Bai Chenguang, Qiu Guibao, Wang Qiang, Wen Liangying, Chen Dengfu, Dong Lingyan, "Preparation and characterization of porous titanium using space-holder technique", *Rare Metals*, Vol. 28, No. 4, Aug 2009, pp 338-342.
8. V. Paserin, S. Marcuson, J. Shu, Cellular Metals: Manufacturing, Properties, Applications, in: J. Banhart, N. Fleck, A. Mortensen (Eds.), Verlag MIT Publishing, Berlin, 2003, pp.31–38.
9. Andrew Kennedy (2012). Porous Metals and Metal Foams Made from Powders, Powder Metallurgy, Dr. Katsuyoshi Kondoh (Ed.), ISBN: 978-953-51-0071-3, InTech.