THE SELECTED PROPERTIES OF FUSION OF FE FOAM AND SHEET METAL WITH USE OF SINTERING IN DISSOCIATED AMMONIA

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Abstract

In the paper there were presented possibilities of combining metal sheet with metallic foams using a sintering powder mixture in dissociated ammonia. The research were carried out over the properties of sintering powder iron foam, with superalloy HASTELLOY® X, by diffusion joint. The results indicated that there's a possibility to obtain the satisfying quality joint between the Fe foam and superalloy HASTELLOY® X. The studies were focused on the properties of microstructure and some mechanical characteristics. Example of structural applications for metallic foams, utilizing benefits in weight, stiffness, energy dissipation, mechanical damping, and vibration frequency were summarized already by many authors. That's why, the author chose to study selected properties of fusion of Fe foam and superalloy sheet metal with new approach. The studies used to determine basic quality parameters of the sintered joint. Using EDS analysis, there were identified a types of alloying elements and the extent of diffusion from superalloy HASTELLOY® X in the course of Fe foam.

Keywords: Fe foam, porous material, superalloy

1. INTRODUCTION

1.1. Production and properties of metal foams

Metal foams are a new type of material with a wide range of applications because of their excellent properties including light weight, impact energy absorption capacity, specific thermal acoustic properties and low thermal conductivity [1, 2, 3]. Nowadays open porous metallic foams are used in heat and mass transfer applications, for instance in heat pipes, vapour chambers, and loop heat pipe elements. In the past few years, there has been a growing interest in metal foams and it is new applications. Both the foam structure and the pore morphology depend on the fabrication method. M.F. Ashby et al. [1] classified the metal foam production methods according to the process and the state of matter. Nine process-routes have been developed and five of them have already been established commercially. They fall into four broad classes: those in which the foam is formed from the vapour phase; those in which the foam is electrodeposited from an aqueous solution; those which depend on liquid-state processing; and those in which the foam is created in the solid state. Each method can be used with a small subset of metals to create a porous material with a limited range of relative densities and cell sizes. Some produce open-cell foams others produce foams in which the majority of the cells are closed. Similar classification was presented in the paper by G.J. Davis et al. [2]. The superior thermal conductivity of copper foams is particularly important. Porous sintered structures can also be produced by sintering small diameter wires.

In the article the author proposes the alternative low-cost technology for fabrication of foams from metals, alloys, intermetallics. The metal foam was formed by a typical base metal like Al, Cu and other [4-7]. The subject of the experiment was tested for using the produced porous metal foams techniques by reduction of metal oxides during the sintering. The mixture was sintered in a dissociated ammonia atmosphere. Fe foam was prepared according to the method described in the Polish patent No. 199720 [8]. However crucial influence on the porosity has the ratio between quantity of metal oxide powder and amount of matrix metal powder, which is a basic structure of produced sinter [9]. This allows for compose of irregular cellular structures with pores open or closed. The foam material can be stacked and co-sintered with top layers to sandwich structures. Porous layers were formed by sintering technique the powder mixture and the reduction of iron powder ASC 100.29, ASC 100.24, DISTALOY SE and iron oxide of different granulation.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1. Materials

HASTELLOY® X alloy is a nickel-chromium-iron-molybdenum alloy that possesses an exceptional combination of oxidation resistance, fabricability and high-temperature strength. It has also been found to be exceptionally resistant to stress-corrosion cracking in petrochemical applications. This alloy has wide use in gas turbine engines for combustion zone components such as transition ducts, combustor cans, spray bars and flame holders as well as in afterburners, tailpipes and cabin heaters. It is recommended for use in industrial furnace applications because it has unusual resistant to oxidizing, reducing and neutral atmospheres.

Table 1 Nominal Chemical Composition, wt. %

Ni	Cr	Fe	Mo	Co	W	C	Mn	Si	B
47[a]	22	18	9	1.5	0.6	0.10	1*	1*	0.008*

[a] represents balance, * maximal level

The chemical composition of powder mixtures: Fe foam was prepared by mixture of iron powder ASC 100.29, ASC 100.25 and Distaloy SE (source Höganäs comp.), Cu powder and iron oxide Fe_2O_3. (Distaloy SE + 12 % Fe_2O_3 + 6 % Cu, in wt. %).

2.2. Fe foam preparing

Fe foam was prepared by mixture of iron powder Distaloy SE (source Höganäs comp.) and iron oxide Fe_2O_3 with different composition. The mixture was sintered in a dissociated ammonia atmosphere at 1180 °C for 45 minutes. After sintering the samples situated in furnace were moved to an area where it was cooled in a protective atmosphere. Cooling took place in with an average speed of about 25 degrees per minute. To determine pore size and shape from the foam specimens, the image analyser software was used. For further study there was selected the foam with an approximating 60 % of porosity.

2.3. Investigation

2.3.1. Micro and macro structure investigation

To illustrate structures of fusion researchers used the optical microscopy and SEM methods. Microscope Nikon MA 200 Eclipse with the image analysis system NIS 4.20 to metallographic specimens testing was used. All samples were mounted in a vacuum, using Buehler EpoThin resin during preparation process for the protection of the porous structure. SEM examination was performed using a JEOL JSM 7100F microscope (with field emission - Schottky) with EDS OXFORD X-MAX microprobe. The results showed that there is a possibility of obtaining a diffusion connection between the Fe foam and HASTELLOY® X.

2.3.2. SEM analysis

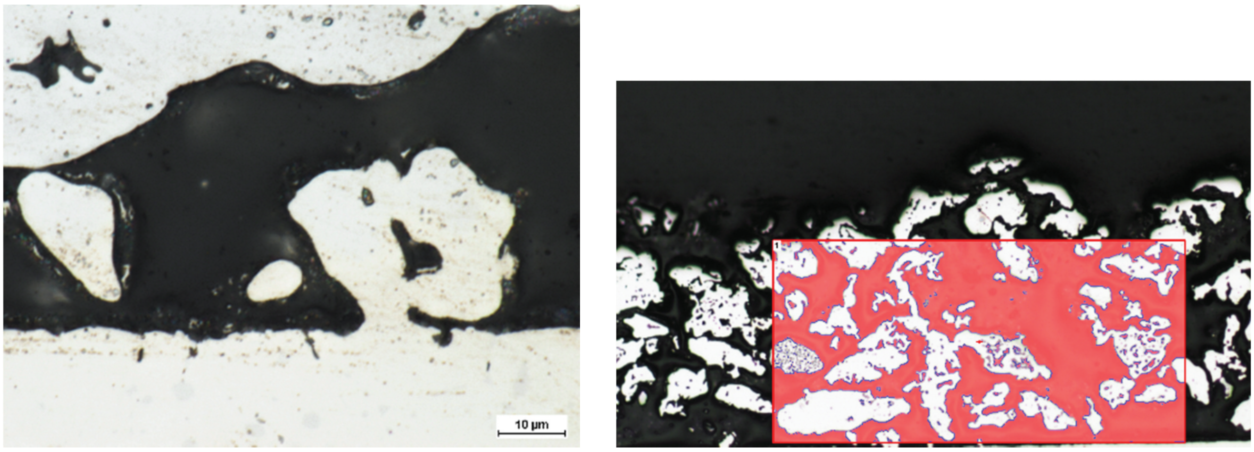
The SEM analysis results showed that there is a possibility of obtaining the diffusion connection between the Fe foam and superalloy HASTELLOY® X. What was important, that sintering process did not occur significant diffusion of Fe in the direction of superalloy HASTELLOY® X. As a result of EDS analysis, there was notified slight diffusion of Fe in the direction of superalloy HASTELLOY® X. Fe diffusion directions towards HASTELLOY® X superalloy, would adversely affect a significant drop in high-temperature properties. During the sintering process has taken place the Cr diffusion in the direction of foam Fe and Cu diffusion in the direction of HASTELLOY® X. Additional studies are required to determine the effects of these phenomena on the properties of the superalloy HASTELLOY® X at the maximum operating temperatures. It was also noted that the diffusion zone is very small. Other chemical analysis carried out at a greater distance from the connection zone did not show Cu diffusion.

3. RESULT AND DISCUSSION

3.1. The observation with optical microscope and image analysis

The porosity was studied using an NIS 4.20 image analyser. **Figure 1a** shows an image of the porous structure of sample Distaloy SE formed on a flat HASTELLOY® X substrate by diffusion bonding.

Considerable expansion of the surface inside the structure was obtained. The non-uniform distribution of pores was received due to diversity of the composition powder particle size. There are bridges connecting porous layer with the superalloy substrate surface.



a) b)

Figure 1 a) The microstructures of the sample porous structure. Not etched;
b) image of cross-section witch marked “ROI`s” in analysed areas

A quantitative analysis of the microstructure of sample was conducted to determine its porosity. It was necessary to define the number of pores per unit considering polished surface for different cross-sections. Five areas so called Region of Interests (ROI) of the structure were analysed. The average porosity was approx. 60 %. **Figure 1b** shows location of ROI for analysed porous layer specimen.

The differences in porosity mainly result from the behaviour of powders during composition. The manufacturing technology defined by the foam morphology is different from the other described structures with pore size and shape [10, 11]. The most similar technology for producing Fe foam described in the literature [12] gives the structure of a much larger pore sizes. In the work there was used additional foaming agent to obtain a greater porosity. This was necessary due to the particular purpose metallic foam. Other methods for preparing porous materials also can produce macroscopic materials having pores like [13] and other. During SEM analysis and EDS microprobe examinations there was no significant diffusion of alloying the diffusion zone from the foam mixture to the substrate material. Only noticeable change in the breakdown of Cu was on the connection zone. Distaloy SE had in its composition approx. 1.5 % Cu. Diffusion occurred at a depth of about 30-40 µm. During the sintering process diffusion of Cu took place, in HASTELLOY® X direction. It was noted that the diffusion zone is very small. **Figure 2** shows microstructure SEM and EDS elements distribution for Fe, Cu and Cr.

The connections obtained by sintering in dissociated ammonia demonstrate morphological characteristic traits for connections of foam with open cells [14, 15]. The pores remained opened outside. As in the case of papers [17-20] there was obtained connection with combination of acceptable parameters. In case of use of techniques such as "joining metals" the metal used for bonding of the foam / foams causes closing the pores. However any comparison with literature data from papers [14 - 18] is difficult to procedure due to the significant differences in the applied materials and techniques combined. Metallographic investigations and EDS analysis demonstrated possibility of use the sintering technique for as difficult to bond materials as metallic foams. In the research there were observed minor changes in hardness within the bonded materials. There was observed low diffusion of the alloying components in the HASTELLOY® X superalloy within the metallic foam. This kind of connection allows fully exploit of properties HASTELLOY® X superalloy. Combining Fe foam with HASTELLOY® X will extend the study over the flow boiling in horizontal and vertical mini-channels. These mini-channels with enhanced walls were performed so far by enhanced heating surface of HASTELLOY® X under different processes: laser texturing, spark erosion and sanding of the surfaces. Till now in the studies HASTELLOY® X thin sheet occurs as a source of heat (electrical heat element) with properly developed surface. However, it caused a significant limitations on modification of surface geometry [19, 20]. The positive experiences from combining H230® and Fe foam provide new opportunities of controlling the processes of heat exchange by modifying the superalloy surface by the foam layer [21].

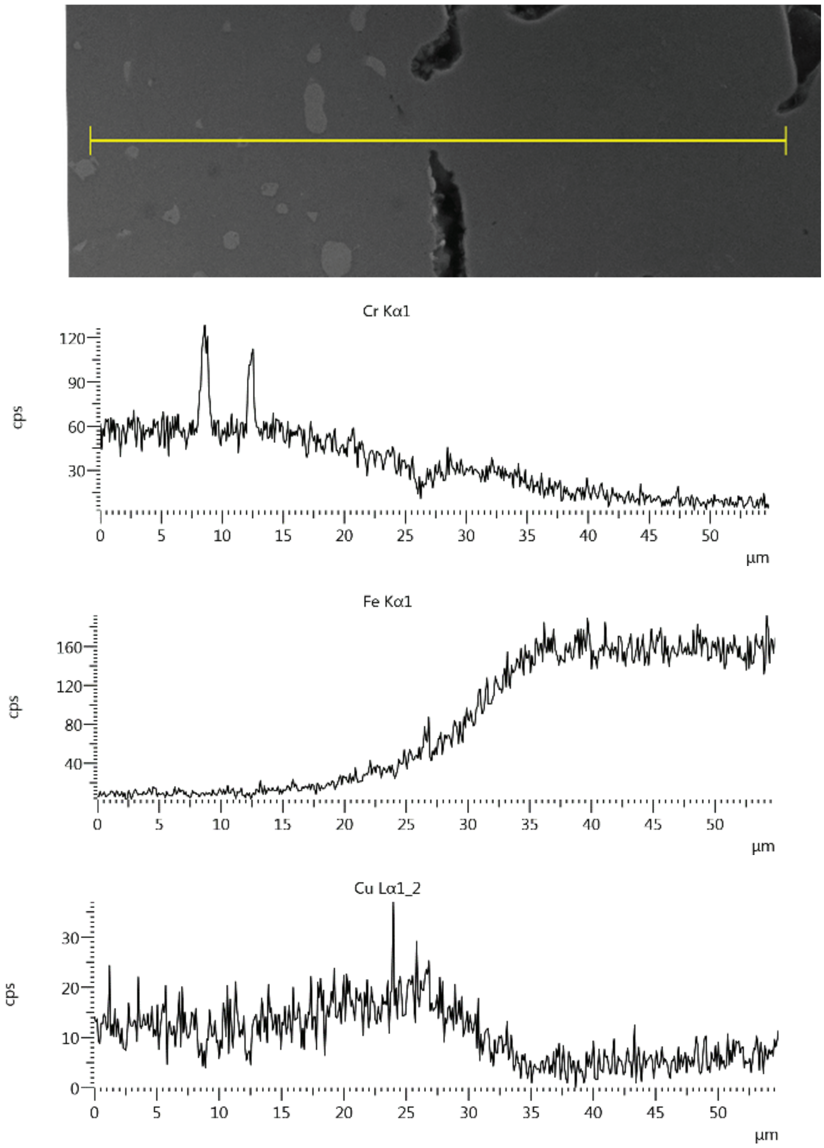


Figure 2 SEM examination of the diffusion bridge between HASTELLOY® and Distaloy SE grain

4. CONCLUSION

Conducted research resulted in widen opportunities of obtaining the satisfying quality diffusion connection between the Fe foam and superalloy HASTELLOY® X. It was important, that there has not been occurred significant diffusion of Fe in direction of HASTELLOY® X superalloy. As a result of EDS analysis there was shown small diffusion of Fe in direction of HASTELLOY® X superalloy. Fe diffusion towards HASTELLOY® X would adversely affect the parameters, and it would mean a significant decrease a high-temperature properties. During the welding process diffusion of Cr in course of foam Fe and Cu in course of HASTELLOY® X took place. Additional studies are recommended to determine the effects of these phenomena on the properties of HASTELLOY® X superalloy at the maximum operating temperatures. Also very small Fe foam diffusion zone was observed. Other chemical analysis carried out at a greater distance from the connection did not show Cu diffusion.

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