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Investigation on the Compressive Behavior of Steel Foams Manufactured by Powder Metallurgy Route

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1- Introduction

Metallic foams or cellular metals as a new class of advanced engineering materials are widely used in the manufacturing of thermal and acoustic insulation, lightweight structures, shock absorbers, heat exchangers, filtration, etc., due to their exclusive properties such as low density, high energy absorption, and high impact toughness, interesting acoustic, and thermal properties. Also, metallic foams have been used successfully in medical applications such as implants and prostheses [1-4]. These materials are successfully manufactured from various metals and alloys. Aluminum has received a lot of attention due to its low weight. Besides, foams of steel, titanium, magnesium, nickel, gold, etc. are also being manufactured and developed [5-7].

Intriguing properties of metallic foams depend on the porosity, cell morphology (open or closed, size, shape, and distribution of cells), the material of cell walls, the thickness of cell walls, and defects, which are often influenced by the manufacturing process [8,9]. The main manufacturing processes of metallic foams include fusion metallurgy and powder metallurgy [1,2]. In the manufacturing of steel foams, due to the high temperature of solidus and other challenges related to melting and casting processes, manufacturing processes based on the powder metallurgy are commonly used [10-12]. Powder metallurgy allows the manufacturing of open cells with uniform shape and size and relatively even distribution [13-15]. Among these processes, the powder metallurgical space holder technique is a widely used method. In this method, iron powders and other additives are mixed with space holder materials in the form of granules, powders, or particles. Then, compaction and leaching processes were sequentially carried out. Finally, the green materials were thermally sintered in the proper conditions [15-18].

Due to the fact that different manufacturing processes have various effects on the mechanical behavior and performance of metallic foams, simulating the mechanical behavior of these materials is essential. The finite element method is often a useful method for estimating the mechanical behavior of metallic foams. It is noteworthy, the simulation results are highly dependent on the way the materials are modeled. In this work, the objective is to manufacture the steel foams through powder metallurgy using urea granules, as spacer holder materials, and to evaluate the compressive properties of steel foams using Gurson-Tvergaard-Needleman model. In addition, the influences of effective parameters on the Gurson-Tvergaard-Needleman equations have been studied.

2- Experimental method

To manufacture the steel foams, a powder metallurgy route based on using urea granules as a space holder was applied. The stages of manufacturing process include: 1) blending powders and additives, 2) coating urea granules by powder mixture, 3) compaction, 4) leaching, and 5) sintering. The density and porosity percentage of manufactured steel foams were determined. To investigate the microstructure of cell walls, an optical microscope (OM) and scanning electron microscope (SEM) were applied. In order to find the mechanical properties, compressive test was conducted on the steel specimens. Also, the Gurson-Tvergaard-Needleman model was used to simulate mechanical properties. The effects of mesh size (L) and effective parameters of the Gurson-Tvergaard-Needleman model (f_n, q_1, and q_2) were studied on the compressive properties of the steel foams.

3- Results and discussion

Morphology of cells. Fig. 1 shows OM and SEM images of the cells and cell walls of the steel foams. It is seen that the cells are formed based on the leaching of the urea granules. The distribution of cells is uniform. Also, the cells formed in some sections are interconnected to each other. It can be related to the applied pressure during the compression stage and the leaching and dissolution of the urea granules by absolute water. The formation of interconnections between the cells has led to the formation of open cells.

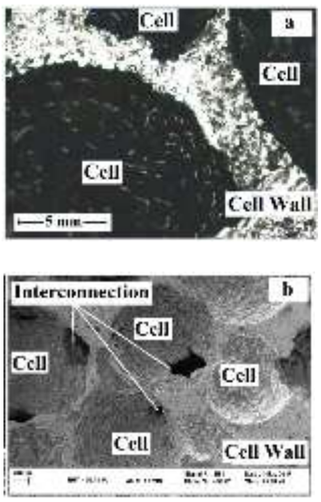

Figure.1. Cells and cell walls a) OM image and b) SEM micrograph.

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Effects of mesh size. The effects of the mesh size on the experimental and simulated compressive stress-strain curves are shown in Fig. 2. The elastic deformation is linearly observed at the beginning of the curves. The linear sections of the simulated curves are exactly the same and are very slightly different from the experimental curve. Therefore, the simulation results in the elastic region are very close to the experimental results, and the mesh size has a little effect in these conditions.

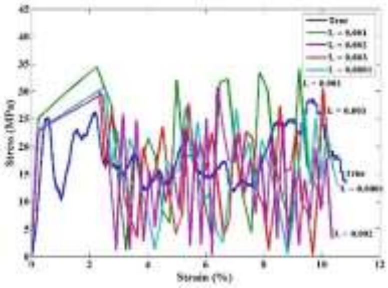

Figure. 2. Effects of mesh size on compressive stress-strain curves at f_n=0.004, q_1=1.25, and q_2=1.75.

Effects of f_n .Fig. 3 shows the results obtained from the change in f_n values on the simulated compressive stress-strain curves. It is seen that the simulated stress-strain curves in the elastic and plastic regions are entirely coincident with each other, and the change in f_n value has little effect on the stress-strain curves.

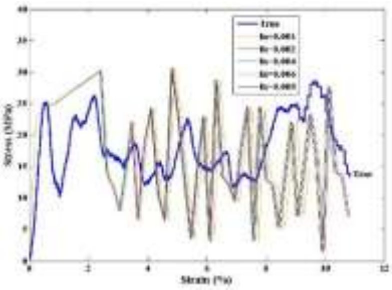

Figure. 3. Effects of f_n on compressive stress-strain curves for L=0.003, q_1=1.25, and q_2=1.75.

Effects of q_1. The effects of q_1 on the compressive stress-strain curves are shown in Fig. 4. It can be observed that unlike fn, q_1 has a strong effect on the compressive stress-strain curves. Increasing the value of q_1 reduces the number of simulated points and the curved shape is out of the saw-tooth. At q_1=1/25, first the linear elastic region and then the saw-tooth plateau region is observed. At q_1=1.5 and q_1=1.75, the number of teeth in the plateau region decreases and at q_1= 2, no teeth are observed.

Effects of q_2. The effects of q_2 on the compressive stress-strain curves are shown in Fig. 5. As it can be seen, the behavior of the simulated stress-strain curves is very close to each other. In all curves, after the elastic region, the long saw-tooth plateau region is formed.

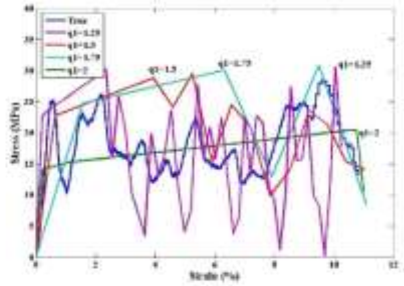

Figure. 4. Effects of q_1 on compressive stress-strain curves for L=0.003, f_n=0.004, and q_2=1.75.

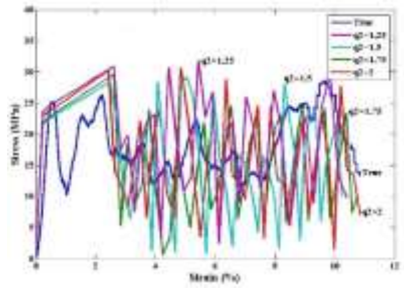

Figure. 5. Effects of q_1 on compressive stress-strain curves for L=0.003, f_n=0.004, and q_1=1.25.

4- Conclusions

In this work, experimental specimens of steel foams were manufacture through powder metallurgical space holder technique, and the porosity, microstructure, and compressive properties of steel foams were investigated. In addition, the effects of simulation parameters from the Gurson-Tvergaard-Needleman equation on the stress-strain curves were evaluated. The following results were obtained.

- The porosity percentage of steel foams was measured to be 79.3%.
- The porosity of steel foams is composed of cells formed on the basis of leaching the urea granules and residual pores between sintered iron particles.
- The microstructure of cell walls is pearlite, which is a phosphorous phase formed in the boundaries of iron particles.
- The formation of phosphorous phases at the boundaries of iron particles leads to the liquid phase sintering and improves the particles bonding.
- The experimental and simulated results of stress-strain curves have an acceptable agreement, especially in the elastic region and in the middle of the plastic region.
- The mesh size, f_n, q_1, and q_2 are effective on the simulated compressive stress-strain curves.
- The effect of f_n and q_2 is not significant compared to q_1. However, changing the value of f_n has the least impact.
- Decreasing the values of q_1 improves the simulation results. At q_1=1.25, the best agreement with the experimental results is observed.