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FABRICATION OF POROUS MATERIAL FROM MILLING SCRAPS

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ABSTRACT

The usage of the recycled machining chips instead of steel powders to produce porous material provides a significant decrease in the raw material consumption and therefore manufacturing cost. In this study, porous steel materials were produced by powder metallurgy technique. For this purpose, SAE 1040 steel milling scraps with different mean chip sizes were firstly cleaned and then mixed with hot paraffin wax solution which was used as a binder. This mixture was compacted into cylindrical form of 10 mm in both height and diameter under 300 MPa pressure and then these green specimens were sintered at 1130 °C for 30 minutes under cracked ammonia atmosphere. The effect of the chip size on the mechanical properties of the sintered samples was evaluated from the characterization studies. Pore morphologies of the samples replicated the initial morphology properties of the chips. Results obtained from the compression tests were discussed in the light of the pore morphology of the samples.

***Keywords*:** SAE 1040 steel, milling scraps, sintering, chip size.

FREZE HURDALARINDAN GÖZENEKLİ MALZEME ÜRETİMİ

ÖZET

Çelik tozları yerine freze talaşlarının geri dönüşümlü olarak kullanılması ile gözenekli malzeme üretimi, hammadde tüketiminde ve dolayısıyla üretim maliyetinde kayda değer bir düşüş sağlamaktadır. Bu çalışmada, gözenekli çelik malzemeler toz metalurjisi tekniği ile üretilmiştir. Söz konusu amaç için; farklı boyutlardaki SAE 1040 çelik hurdaları öncelikle, temizlenmiştir ve daha sonra bağlayıcı malzeme olarak kullanılan sıcak parafin çözeltisi ile karıştırılmıştır. Karışım, 300 MPa basınç altında, çapı ve yüksekliği 10 mm olan ham numuneler elde edilecek şekilde preslenmiş ve 1130 °C'de parçalanmış amonyak atmosferi altında 30 dakika boyunca sinterlenmiştir. Talaş boyutunun sinterlenmiş numunelerin mekanik özellikleri üzerindeki etkileri yapılan karakterizasyon çalışmaları ile değerlendirilmiştir. Üretilen numunelerin gözenek morfolojisi, talaşların başlangıçtaki morfolojik özelliklerini yansıtmaktadır. Basma testlerinden alınan sonuçlar, numunelerin gözenek morfolojileri göz önünde bulundurularak irdelenmiştir.

***Anahtar kelimeler*:** SAE 1040 çeliği, freze hurdaları, sinterleme, talaş boyu.

1. INTRODUCTION

Porous metals have recently attracted considerable attention in both academia and industry because of their exceptional mechanical, thermal and acoustic properties [1]. Nowadays demand for porous steel is increased in many fields, such as functional and structural applications. There are several methods for the production of porous metals which can be classified into liquid or solid state. Melt-gas injection, melt-foaming agent, casting, electro deposition, infiltration and powder metallurgy techniques can be given as some of the examples for the production methods of porous metals [2-3]. Powder metallurgy (PM) technique was utilized in this study owing to its advantages such as being an environmentally friendly and economical method, the chance of using a wide range of metal powders like aluminum, stainless steel, magnesium, copper, nickel as the starting material and the possibility of obtaining products with complex shapes and structures. In this regard, porous metal production from scraps, which are the main waste of metal manufacturing sector, by PM technique appears to be a feasible way.

SAE 1040 steel is structural and mechanical steel for general purpose. The typical uses of SAE 1040 steel include machine, plow, and carriage bolts, tie wire, cylinder head studs, and machined parts, U-bolts, concrete reinforcing rods, forgings, and non-critical springs. Therefore machining of the semi-finished products causes a considerable amount of chip form waste during the manufacturing processes of these steel parts [4]. Since recycling of these waste materials is difficult, it is essential to develop a method for converting them into useful industrial components. Today, source deficiency and environment pollution become ever more significant. In order to preclude these problems, sufficient importance should be attached to the recycling applications. Hereby, benefits such as prevention of the excessive consumption of the natural raw materials, reduction in processing costs and less pollution by releasing less waste to the environment will be provided [5].

In the past years, several researchers worked on obtaining porous aluminum and magnesium by PM technique from scraps and determined the mechanical and microstructural properties of the specimens [6-11]. However, there is no study on porous SAE 1040 steel in the literature and in this study, porous metal have been obtained from SAE 1040 steel milling scraps by PM technique; hence it can be described as a novel method among the other researches. Basis of this study depends on the production of porous metals from low cost machined chip wastes instead of steel powders by performing the steps; cleaning of the chips from surface contamination like oxides and oil, mixing of the chips and the binder, compaction of this mixture and sintering, respectively. The aim of the present work is to investigate the mechanical properties of the samples produced from SAE 1040 steel machined waste chips with various sizes by PM technique.

2. EXPERIMENTAL PROCEDURES

In this study, SAE 1040 steel milling scraps with different mean chip sizes were used for porous steel production. They are real waste which comes from Bor Cutting Tool Industry and Trade Limited Company. Binder for green strength was paraffin wax, supplied by Merck, Germany. Table 1 presents the chemical composition of the SAE 1040 steel. SAE steel chips were meshed to three mean chip sizes and the typical morphologies of the chips after ultrasonic cleaning with ethyl alcohol solution and drying at 60 °C for 30 minutes are shown in Figure 1.

Table 1. Chemical composition of the SAE 1040 steel chips used (wt%).

Material	C	Si	Mn	P	S	Cr	Ni	Mo	W	V	Al	Fe
SAE 1040	0.42	0.35	0.65	0.025	0.015	0.10	0.12	0.01	0.02	0.001	0.001	0.9828

Figure 1. Images of the SAE 1040 steel chips having mean size of (a) 4 mm, (b) 6 mm and (c) 8 mm.

The manufacturing process of porous metals from SAE 1040 steel milling scraps includes four stages: cleaning of the chips from surface contamination like oxides and oil, mixing of the chips and the binder, compaction of this mixture and sintering. Initially, paraffin wax solution, which consists of 5 wt%, was added to the steel chips as the binder and the steel chips were mixed manually with this hot paraffin wax solution. The blended chips were then compacted uniaxially at 300 MPa in a steel die by using a hydraulic press into cylindrical specimens with a diameter of 10 mm and height of about 10 mm. The specimens were sintered at 1130 ºC for 30 minutes in an industrial continuous pusher furnace under 25% N_2 - 75% H_2 (cracked ammonia) atmosphere. A schematic illustration of the manufacturing process is shown in Figure 2.

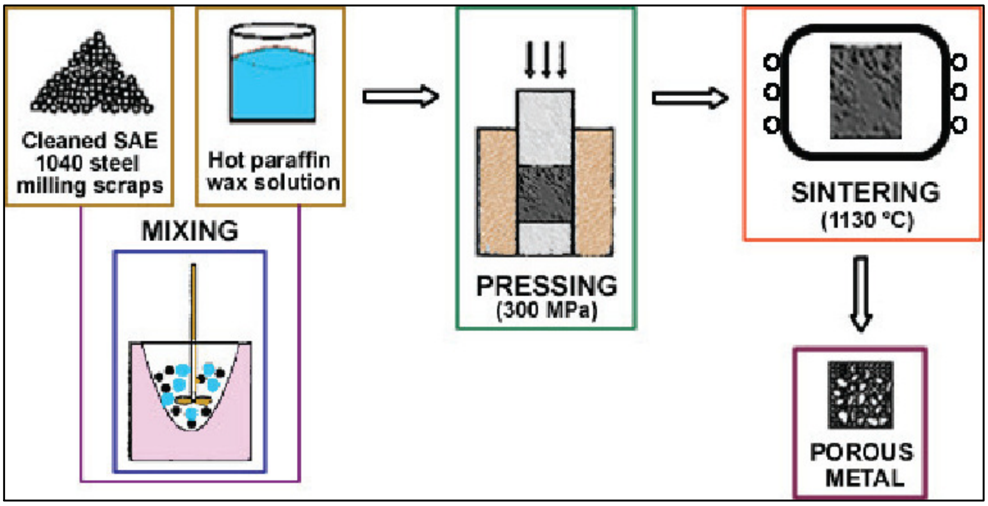

Figure 2. Schematic diagram of the processing stages for the production of porous metal from milling scraps by PM technique.

Density and porosity content of the sintered porous steel specimens were determined by employing Archimedes' principle in a Sartorius precision balance equipped with a density-determination kit. At least five specimens were used for characterizing each porosity level. Pore morphologies of the produced specimens were examined using Olympus, PME3 optical microscope. Mechanical properties of the porous specimens were investigated at room temperature using the Zwick-Roell Z050 Testing Machine fitted with a 50 kN load cell operating at the displacement control mode, with a strain rate of 0.5 mm min^{-1}. Each test was repeated three times to ensure the repeatability of the results.

3. RESULTS AND DISCUSSION

Specimens with porosities in the range of 34.1-39.1% were successfully produced by PM technique from milling scraps with different mean chip sizes. Total porosity of the specimens consists of 19.3-26.8% open and 12.3-14.9% closed porosity. Figure 3 illustrates sintered porous specimens fabricated using different mean chip sizes. Typical macro morphologies of the porous specimens fabricated using different mean chip sizes are shown in Figure 4. Pore size of the specimens is strongly related to the chip size. Since chips were used instead of powders, the obtained porous specimens possess wide macropores. It can be seen that the pore shape of all specimens replicated the initial shape of the SAE 1040 chips. Porous steel products manufactured from chips with smaller chip size display smaller pores. No cracks were observed in these porous structures. A detailed microstucture investigation in terms of bond formation between pore walls of the chips is out of the scope of this study and will be carried out in the further researches.

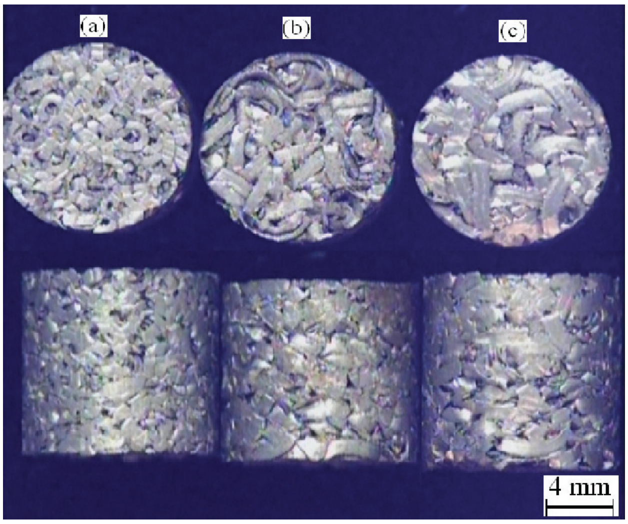

Figure 3. Sintered porous specimens fabricated using the mean chip sizes (a) 4 mm, (b) 6 mm and (c) 8 mm.

Figure 4. Typical morphologies of the porous specimens produced using the mean chip sizes (a) 4 mm, (b) 6 mm and (c) 8 mm.

Mechanical properties of the sintered porous steels were evaluated in compression test. The compressive stress-strain curves of porous specimens fabricated using different mean chip sizes are illustrated in Figure 5.

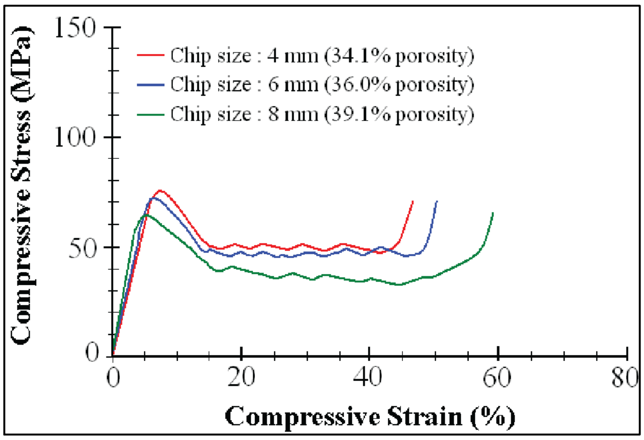

Figure 5. Compressive stress-strain curves of the porous SAE 1040 specimens fabricated using different mean chip sizes.

The present porous steels show a similar compression behavior compared to the other metal foams produced using machining scraps [6, 12], characterized by three distinct regions, (i) stress rising linearly with strain at low stresses (elastic deformation), followed by (ii) along deformation plateau during which the pore walls buckled and collapsed and then (iii) a densification regime where the pore walls come in contact one with another, causing an abrupt rise in the flow stress.

Size of the chips affects the compressive behavior. It can be recognized that decreasing the chip size leads to an increase in the compressive yield stress. Specimens with small chip size showed higher compressive stress than the specimens with large chip size. The larger the pore size is, the smaller the mean stress acts upon the pore of the material. However, in order to observe this effect clearly, studies should be done by using chip sizes different than the ones we have chosen. Moloodi and Raiszadeh [6] studied the effect of the chip size on the mechanical properties of aluminum foams produced from turning scraps by PM technique and found out that decreasing the chip size, down to a chip size of about 0.5 mm, increased the compressive stress.

The obtained porous SAE 1040 steels show lower compressive yield stress due to using chips instead of steel powders. Because of using chips, surface area decreased and a weaker bonding between SAE 1040 chips occurred. Therefore the produced structures exhibit lower compression stress. Specimens deformed heavily with the applied load depending on solid phase bonding between matrix chips. Weak bonding behavior of the chips can be attributed to the solid-state sintering mechanism.

4. CONCLUSIONS

SAE 1040 steel specimens with porosities in the range of 34.1-39.1% were fabricated by PM technique. Compressive response of the sintered specimens and their pore morphologies were evaluated. The following conclusions about the achieved results were drawn:

- ✓ The possibility of fabricating porous SAE 1040 steel specimens from milling scraps by PM technique was confirmed. PM technique not only allows the usage of waste materials such as scraps but also it is a clean production method so that, it can be defined as a green process.
- ✓ Compression behavior and pore morphologies of these porous SAE 1040 steels can be modified if the chip size is changed.
- ✓ Pore size of the specimens is strongly restricted by the chip size used. Since chips have been used instead of powders, the obtained porous specimens possess wide macropores. Porous steel products manufactured from the chips with smaller size showed smaller pores. No cracks were observed in these porous structures.
- ✓ Decreasing the chip size increased the strength of the porous specimens due to the decrease in pore size and hence increased the porous specimens' density. However, in order to concretize this result, studies should be done with the average chip sizes under 4 mm.
- ✓ From these results, it was determined that it may be possible to improve the mechanical properties of the porous steel, if higher sintering temperatures and time is applied, techniques for compacting under higher pressures are developed, chips with smaller sizes are used or alloying elements are added to provide liquid-phase sintering.
- ✓ Preliminary results obtained from the tests applied to the porous steels produced from SAE 1040 steel milling scraps by PM technique indicated the feasibility of the method for porous material production from waste materials released after the iron and steel manufacturing processes. Consequently, it can be specified that porous metal production can be achieved from also other waste metal scraps by PM technique.

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