# Recycling of Stainless Steel Grinding Sludge

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**Abstract**

*Stainless steel sludge is generated as a waste in the grinding process, and the possibility of recycling stainless steel is considered here. In this study, we considered the possibility of using the stainless steel sludge as metal powder for MIM or raw material for metal foam. For the MIM process, the metal powder will need some improvement, and flotation and spheroidizing processes of the sludge are necessary. For fabrication of the metal foam, untreated sludge can be used, and steel foam about 90% porosity is produced.*

**Keywords: recycle, stainless steel sludge, flotation, spheroidizing, plasma**

## 1. Introduction

Grinding sludge is generated from machining factories and most of them are re-melted with scrap steel or discarded. Especially, in a ball bearing factory, stainless steel powder is generated, and most of them are discarded. In this study, we considered the possibility of recycling the metal sludge, and two processes wear developed for this. One process is purifying and improving the quality of the sludge, and use it as the raw powder for MIM process. [1] For purification, flotation process is necessary. For spheroidizing, plasma spray process is used, and magnetic concentration is used to eliminate the abrasive grain. Another process is using the sludge as a raw material for metal foam production. For this process, the sludge is used without purification, and hydro-gel process [2] is used to produce the high porosity metal foam.

## 2. Preparation of MIM Powder

Stainless steel sludge generated at Santoku Co. was used as a raw sludge powder. However, this sludge contains tool steel or other kinds of steels. Therefore, it needs to purify and increase the stainless steel content. To separate the stainless steel sludge from other sludge, the floatation method was used. [3] After floatation, the sludge was spheroidized using plasma. Spheroidized powder was slightly magnetized, and abrasive grain was removed by magnetic concentration.

### Flotation

In flotation, grinding sludge is mixed with water, frothing reagents, and collecting reagents. When air is blown through the mixture, stainless steel cling to the bubbles, which rise to form a froth on the surface. Other sludge settles to the bottom, and the froth is skimmed off, and water and chemicals are distilled.

### Spheroidizing

Sludge powder was spheroidized using plasma spray process. Sludge powder was fed by 245 g/min using argon gas, and supplied D.C. current for plasma is 350A. The schematic diagram of plasma spray equipment is shown in Fig. 2, and sludge is spheroidized while passing though the plasma jet.

### Magnetic concentration

Abrasive grain was removed from spheroidized powder using magnetic concentration. Spheriodized powder was slightly the magnetized, and they were trapped on magnet bar. The abrasive grain settled at the bottom. After magnetic concentration, about 60% of raw sludge remained.

## 3. MIM Process and Mechanical Properties of Recycled Powder

Using the powder from sludge, MIM process is tried. For the debinding, the super critical carbon dioxide was used. The debound body was sintered in 1673K for 2 hours. Mechanical and physical properties of the sintered specimens are shown in Table 2. These specimens were compared with the results with popular specimens where stainless steel powder was used for MIM (Epson-Atmix, PF-20). Using the sludge powder, the specimens showed relative density of 92.1%, which is not enough. They have UTS over 500 MPa and high hardness comparing with

**Table 1. Density and mechanical properties of MIM parts made from sludge and popular stainless steel powder**

| Used powder | Relative Density(%) | UTS (M Pa) | Elongation (%) | Young's modulus (G Pa) | Vickers Hardness (HV) |
|---|---|---|---|---|---|
| Powder from sludge | 92.1 | 591 | 7.1 | 122 | 182 |
| PF-20F, Epson-Atmix | 96.2 | 522 | 46.0 | 161 | 120 |

SUS304 stainless steel MIM parts. However, their elongation is less than 10%.

### 4. Production Process of Metal Foam

In this process, a slurry containing a metal powder, a foaming agent, and a surfactant in an aqueous polymer solution was prepared. It had the ability to form a gel. This slurry was gelled under conditions suited for the nature of the aqueous polymer solution. After gelation, the slurry was heated until the foaming agent started to produce foam. After drying, a precursor of the metal foam was obtained. This was sintered to form the metal foam. The selection of the hydro gel binder and the foaming agent is important in this process. The hydro gel needs to have the correct viscosity to produce a cellular structure at the foaming temperature. In this process, we used an aqueous solution of PVA( poly vinyl alcohol) as the hydro gel binder. Pentane and *n*-hexane were used as the foaming agents. Aqueous PVA solution form gels following a freezing and thawing process[4], and the gels are re-melting at about 320–330 K.

### 5. Properties of Metal Foam Using Sludge Powder

Concentrations of prepared slurry and porosities of sintered metal foams are shown in Table 1. To obtain the high porosity foam, the powder that is mixed with the sludge and MIM powder is recommended. However, MIM powder is expensive and only sludge powder is recommended for the low cost foam. As the foaming agent, *n*-hexane is more efficient than pentane, and efficiency of the forming agent content depend on the used powder. The metal foam of over 90% porosity can be produced by using the sludge powder, and the metal foam of over 95% porosity can be produced using the mixed powder.

### 6. Summary

In this study, we investigated the possibility of recycling the stainless steel grinding sludge was investigated. Using flotation, spheroidizing and magnetic concentration processes, the powder was prepared and tested in MIM. However, the quality of the powder was poor, and the sintered parts had low density and low elongation. This is attributed to the poor level of purity of the powder, and that the surface of powder is highly oxidized. In addition, the sludge was used as the raw material of the metal foam. Using hydro-gel process, a high porosity metal foam could be produced. Thus, mixing the sludge powder with MIM powder is recommended for producing higher porosity metal foam. Lastly, the metal foam can be applied the application as the heat resistance material, sound absorbing material or shock absorbing material.

**Table 2. Conditions of metal foam production from grinding sludge and the porosities**

| Used powder (Sludge powder: PF20-F) | Foaming agent | Concentration of the agent in binder (%) | Porosity (%) |
|---|---|---|---|
| 100 : 0 | hexane | 10 | 92 |
| 100 : 0 | hexane | 20 | 90 |
| 100 : 0 | pentane | 10 | 89 |
| 50 : 50 | hexane | 10 | 96 |
| 50 : 50 | hexane | 20 | 94 |
| 50 : 50 | pentane | 10 | 93 |

### 7. References


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