POSSIBILITIES OF USING POWDER METALLURGY TO PRODUCE PISTOL BULLETS

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Abstract

Powder metallurgy is widely used in technical practice to manufacture products with specific properties. In the field of ammunition, powder metallurgy technology is used to produce frangible bullets designed for fire arms.

This paper presents results of pressing of experimental cylindrical samples from mixture of Fe - Sn metal powders. The samples with the diameter of 9 mm were compacted by cold pressing in cylindrical rigid die without additional sintering. By changing the axial pressing force in the range of 10 to 40 kN various physical and mechanical properties of the produced samples were achieved. The determined mechanical properties of manufactured specimens are an important input for the further development of pistol frangible bullets of 9 mm calibre.

Keywords: Powder metallurgy, mixture powder Fe-Sn, frangible bullet, green density, green strength

1. INTRODUCTION

In recent years the powder metallurgy technology is used for the manufacturing of ammunition for fire arms. Projectiles manufactured this way are called frangible bullets. These bullets are mostly made of material based on copper powder. Many types of frangible projectiles with different properties are nowadays available on the market. The most famous of them is an American company Sinterfire that produces brittle frangible bullets since 1998. In the Czech Republic the first round with a frangible projectile 9 mm Luger SR (Svachouček - Rydlo) was developed in the years 2006-2009. The bullet SR was made on the basis of mixture of Fe-Sn metal powders.

Follow up the research of Ing. Rydlo and the development activities at the Department of Weapon and Ammunition - University of Defence in Brno, the samples from mixture of Fe-Sn metal powder with polymer binder were produced by uniaxial compaction on the hydraulic press without subsequent sintering. In this article the relationships between the green density / green strength of the samples (cylindrical samples) on the pressing pressure have been presented.

2. EXPERIMENT

To produce the samples, a mixture of Fe (49.5%) - Sn (49.5%) metal powders with binder Acrawax C (1%) of the total weight 5 g was used. The samples were cold compacted in a rigid cylindrical die with internal diameter of $9.00^{+0.05}$ mm using a hydraulic press for the compaction. The die-wall was lubricated with zinc stearate. The pressing force was varied in the range of 10 to 40 kN with a step of 5 kN. The pressing speed of 50 mm/min was applied for each compaction.

As the first step for description of the material properties, the bulk density of the mixture was determined by measuring the volume of the mixture in the die at zero compaction pressure. The average value of the apparent density was 3414 kg.m^{-3}. The green density was calculated from the volume and the weight of the test specimen.

After compaction the samples were subjected to the test of strength in axial compression. The compressive load in the axial direction corresponds the best way to the real load of the frangible bullet and enables also to determine the normalised characteristics of the material that can be used for further development activities.

3. RESULTS

Summarizing the results of the compaction and mechanical test of the samples, the corresponding compaction pressure and other important parameters of used technology are listed in **Table 1**. The height of the samples varied from 11.2 mm to 12.7 mm, their green density varied from 6120 kg.m^{-3} to 6910 kg.m^{-3} depending on the pressing pressure. Compared to the apparent density, the green density of the samples increased 1.8 times to 2 times.

Table 1 The results of pressing of the mixture Fe-Sn metal powders

Pressing force (kN)	**Compaction pressure** (MPa)	**Height of specimen** (mm)	**Green density** (kg.m^{-3})	**Modulus of elasticity in compression** (MPa)	**Green strength in compression** (MPa)	**The maximum compressive strain** (1)
10	156	12.70	6120	4754	50.63	0.0107
15	233	12.01	6450	4565	60.51	0.0132
20	311	11.69	6640	4406	66.87	0.0152
25	389	11.48	6760	4415	68.78	0.0156
30	466	11.35	6830	3943	71.60	0.0181
35	544	11.33	6850	3531	72.08	0.0204
40	622	11.23	6910	3330	71.47	0.0215

Based on the measurement results, the relationship between the green density on the pressing force (compaction pressure) was obtained. The dependence of green density on the compaction pressure was approximated by exponential function (**Figure 1**).

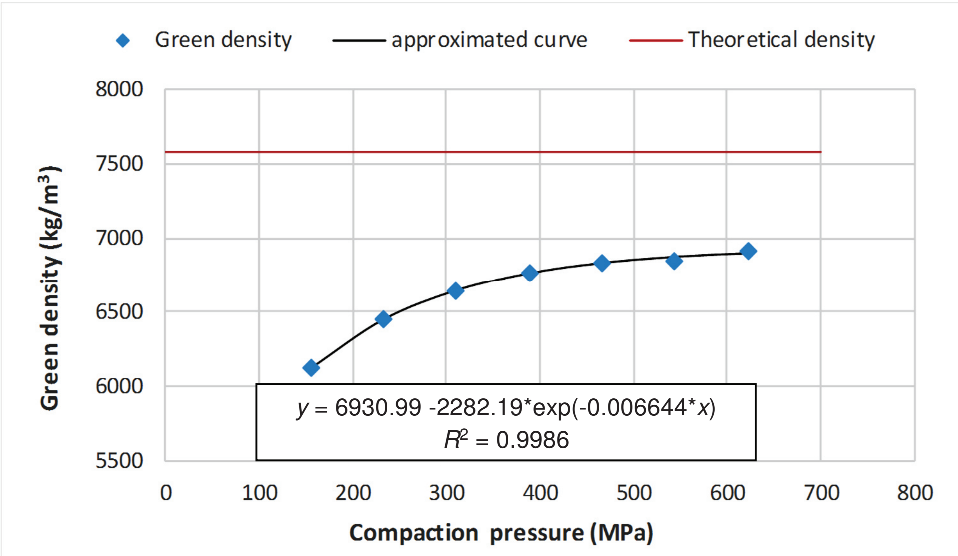


Figure 1 Dependence of green density of the samples on the compaction pressure

The results indicate that the green density of the samples asymptotically approaches to the limit of almost 7000 kg.m^{-3}. The green density rapidly increases until the pressing force of 30 kN (466 MPa). After reaching the pressing force of 30 kN the green density increases slowly and is almost constant. For comparison, in the

Figure 1 the value of the theoretical density 7580 kg.m^{-3} of the alloy Fe/Sn 50/50 is shown, which were unattainable for the samples even under the extreme compaction pressure.

During the test of strength in uniaxial compression, the information about the changes of the load and deformation of the samples was saved. The dependences of the axial uniaxial compressive stress on the relative deformation (compressive strain) of the samples are shown in **Figure 2**.

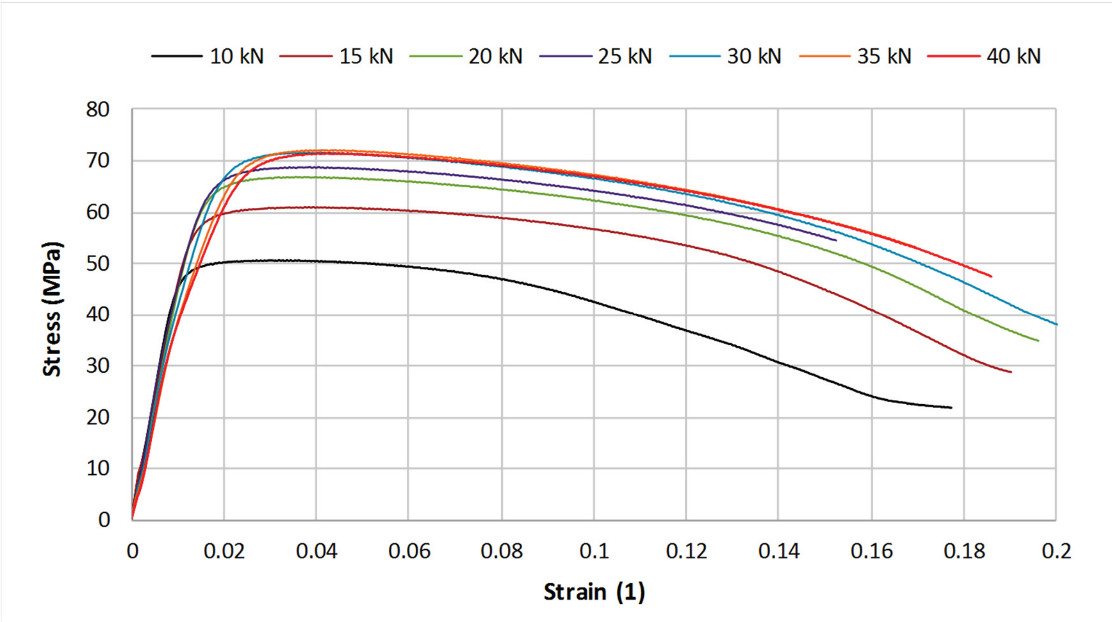


Figure 2 Dependence of stress on strain in test of compressive strength

The dependence of uniaxial compressive strength of the samples on compaction pressure by approximation of exponential function is supplemented on the **Figure 3**. As the green density the green strength in compression of the samples increases in the range of pressing force of 10-30 kN. With further increasing of pressing force the green strength of the samples increases to a limited extent and reaches a maximum of 72 MPa. From **Figure 3**, it is clear that the green strength could be effectively increased in pressing force of 30-35 kN. The further increasing of the green strength is possible only by optimizing the composition of the material.

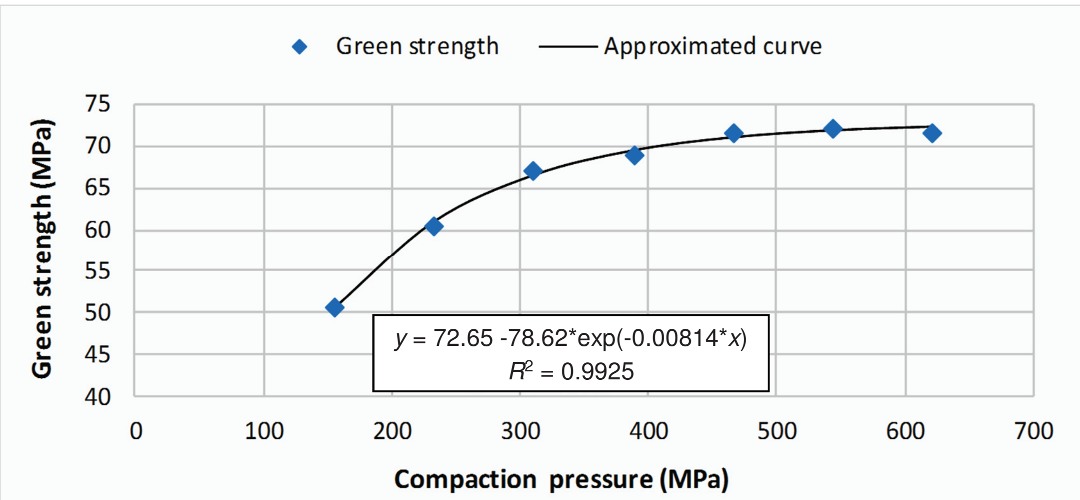


Figure 3 Dependence of green strength in compression on compaction pressure

The compaction process can be described by a series of theoretical models that express the material behaviour during the compaction (e.g. models Kawakita, Heckel and Penelli-AmrosioFilho, etc. [4, 6]). According to Kawakita the compaction pressure is related to green density as the following equation:

$$\frac{p}{C} = \frac{1}{a}p + \frac{1}{ab}; \ where: C = \frac{V_0 - V}{V_0} = \frac{\rho_p - \rho_a}{\rho_p},$$

where: V_0 - apparent volume; V - volume at pressure p; a, b - powder constants; ρ_a - apparent density; ρ_p - density at pressure p.

From the experimental data a linear graph of relationship $p/C = f(p)$ was obtained and shown in **Figure 4**. The values of constants a and b were found.

$$\frac{1}{a} = 1.8862; b = 0.03417$$

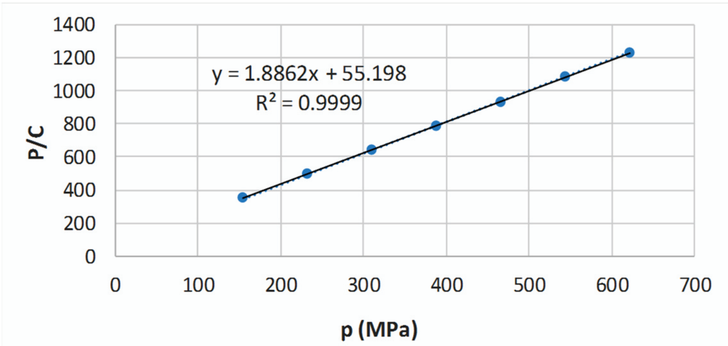
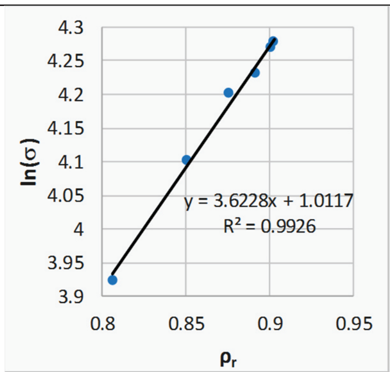
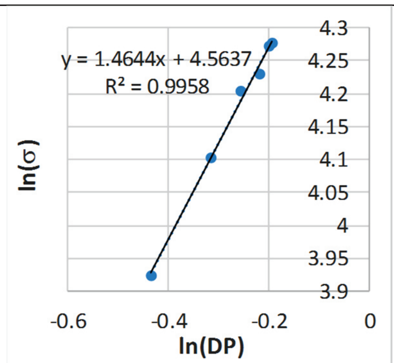
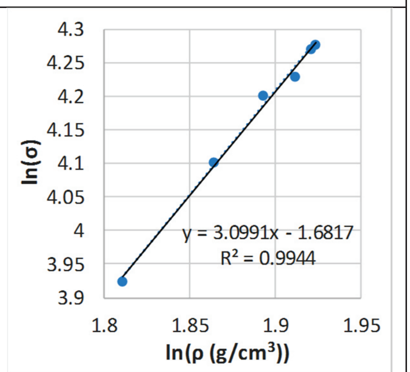


Figure 4 Plot obtained for the model Kawakita for the powder mixture Fe-Sn

In some literatures the relationships between green strength in compression and green density/ green relative density of the samples are described [1-2, 7-8]. Some of them are listed in **Table 2**, the values were experimentally determined by testing strength in compression of the samples.

Table 2 Material models of relationship between green strength and green density during compaction for the mixture Fe-Sn metal powders (in the logarithmic scale)

Duckworth	Halldin	German
$\sigma = K_D \exp(m_D \rho_r)$	$\sigma = K_H DP^{m_H}$; where $DP = \frac{\rho - \rho_a}{\rho_t - \rho_a}$	$\sigma = \frac{K_G}{\rho^{m_G}}$
where : σ - green strength; K_D, m_D, K_H, m_H, K_G, m_G - material and powder constants; DP - densification parameter; ρ - green density; ρ_r - relative density; ρ_t - theoretical density ; ρ_a - apparent density.		
		
K_D = 2.7503; m_D = 3.6228	K_H = 95.9378; m_H = 1.4644	K_G = 0.1861; m_G = -3.0991

4. DISCUSSION

First shooting experiments have shown that the selected material offers optimal mechanical properties for the desired pistol frangible bullets. In order to describe the material mechanical properties and material density in relationship with the compacting parameters the aforementioned trials were performed and the validity of the theoretical models describing the material compaction were checked. The results of these trials are very important input in the further development of the frangible bullet. With known relationship between the compaction pressure and material density the shape of the frangible bullet of required mass can be defined. Known relationships between the volume of powder and compacting forces will be used for development of the manufacturing tools as well as for the definition of the requirements for manufacturing equipment. Confirmed validity of theoretical models for powder compaction will simplify any potential changes in the metal powders (distribution of the size of the powder grains, changes in the powder mixing …) by means of experimental description of the model constants and theoretical prediction of the material behaviour at the compaction.

5. CONCLUSION

The results of experiments confirm that the green density of the samples produced by mixture of Fe - Sn metal powders asymptotically approach to the limit of almost 7000 kg.m^{-3}. The green density of the samples increases until the pressing force of 30 kN (corresponding to axial pressure of 466 MPa). After exceeding the pressing force of 30 kN the green density slowly increases and is virtually immutable. Similar conclusions as for green density also apply to the green strength of the samples in compression, its limited value reaches 72 MPa. The results could be applied in the development of frangible bullets of 9 mm calibre.

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