EFFECT OF CARBON ADDITION MODE COATING ON THE COMPACTION BEHAVIOUR OF Fe-Cr-Mo-C POWDERS

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Abstract
The paper deals with the analysis of the effect of carbon coating and carbon admixing on the compressibility of Astaloy CrL powder and on its specific compressibility. The apparent density of the powder mixes was determined according to MPIF Standard 04. A set of test specimen 12x10 mm was uniaxially pressed in a hardened steel die. Zinc stearate in acetone solution was used as wall lubricant. Compaction pressures ranged from 50 MPa up to 600 MPa. Considering the densification of metal powders in a uniaxial compaction, the compressibility equation, proposed by Dudrová, Parilák and Rudnayová has been used. Compressibility parameters were calculated by linear regression analysis using the linear form of equation. The development of compressibility values with pressing pressure enables to characterise the effect of particles geometry and matrix plasticity on the compaction process. In order to achieve a higher plasticity, carbon coating has to be preferred to carbon admixing; the coating has also a positive effect on the compaction behavior of Astaloy CrL powders.
Keywords: compaction, compressibility, density, porosity, carbon addition mode

INTRODUCTION

The compressibility of metallic powders depends on many factors, including the morphological and mechanical properties of particles. Metal powders represent a statistical set particles with different morphological properties (size distribution, shape, specific surface) and mechanical properties (hardness, yield strength, hardening rate, etc.)

Considering the densification of metal powders in a uniaxial compaction, the compressibility equation, proposed by authors [1-4], was used:

$$P = P_0 \cdot \exp\left(-K \cdot p^n\right) \qquad (1)$$

where:
P - porosity achieved at an applied pressure p;
P_0 - apparent porosity calculated from the value of the experimentally estimated apparent density; p - applied pressure;
K - parameter related to particle morphology;
n - parameter related to activity of powders to densification by the plastic deformation.

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Considering the n = 1 can be expressed particle packing without plastic deformation as:

$$P_1 = P_0 \cdot \exp(-K \cdot p) \tag{2}$$

The equation (2) enables to calculate the „fictive" pressure p_1, which designates the value of the pressure p necessary for achieving $P_1 \to 0$ only by movements of particles without (in the case of very hard particles) or with some small plastic deformation development at the contacts of particles (in the case of plastic material) during the compaction process:

$$p_1 = \frac{\ln(P_0) - \ln(P)}{K} \tag{3}$$

where p_1 is calculated for P = 0.1 %..

Using the linear form of equation (1):

$$\ln\left(\ln\left(\frac{P_0}{P}\right)\right) = -\ln K + n \cdot \ln p \tag{4}$$

the parameters K and n can be calculated by mathematical modelling using linear regression analysis. Mathematical modelling and numerical analysis is a proven and reliable technique for analyzing various forming processes [5-8]

A linear relationship between the parameters K and n was found in [9]:

$$\ln K = f(p): \ \ln K = a - b \cdot n; \tag{5}$$

and the validity of the equation (4) was tested for 109 different metallic powders, where the regression parameters were [9]:

a = 1.432

b = 7.6

and correlation coefficient, r = 0.9665.

Considering the equations (1), (4) and (5), parameters K and n are "integral" parameters characterising the compaction process of metal powder for pressing pressures ranging from p=0 to p→∞. The porosity achieved at any instantaneous pressure p_i is the result of the interaction between the instantaneous values of K_p and n_p. Assuming the interaction between the parameters K_p and n_p their dependence from equation (5) on the pressing pressure p can be calculated using the values from equation (4):

$$n_p = \frac{\left[\ln\left(\ln\left(\frac{P_0}{P}\right)\right) - 1.423\right]}{[\ln(p) - 7.6]} \tag{4}$$

$$K_p = 4.187 \cdot \exp(-7.6 \cdot n_p) \tag{5}$$

The development of the values K_p and n_p with pressing pressure p enables one to characterise the effect of particle geometry and matrix plasticity on the compaction process. The higher the decrease of the parameter n_p with the pressure p, the higher the capacity of plastic deforms. The higher the increase of the parameter K_p with the pressure p, the lower the effect of the particle geometry on the compaction behaviour of the powder.

The aim of this work is quantification of the effect of carbon coating and carbon admixing on the compressibility of ASTALOY CrL powder, and to specify the values of parameters K and n.

MATERIAL AND EXPERIMENTAL PROCEDURES

For the preparation of the test specimens the following materials were used:

- water atomized prealloyed Astaloy CrL powder (Höganäs AB),
- natural graphite CR12 (Grafit Netolice).

The experimental systems are presented in Table 1.

Tab.1. Experimental systems.

System	Marking
Astaloy CrL + 1.02% C - admixed	A
Astaloy CrL + 1.02% C - coated	B
Astaloy CrL	C

System A was admixed from Astaloy CrL and graphite powders. System B was consist of carbon coating of Astaloy CrL. Carbon as a solid C_nH_m hydrocarbon powder was derived by means of equipment entirely developed in the IMS BAS Sofia. System C was "pure" Astaloy CrL powder.

The morphology of the powder particles was characterised by the friction index proposed by Hausner [10]. The apparent density of powders was determined according to [11].

A set of tools to produce a test specimen 10x12 mm were uniaxially pressed in a hardened steel die. Zinc stearate in acetone solution was used as die lubricant. The green compacts were weighed with an accuracy of ±0.001 g. The dimensions were measured with a micrometer calliper (±0.01 mm). Compaction pressures ranged from 50 MPa up to 600 MPa. The procedure is described in [12, 13].

RESULTS

Table 2 showed input data for calculated compressibility parameters.

Tab.2. Input data for calculated compressibility parameters

Material	apparent density ρ_a [g·cm^{-3}]	tap density ρ_t [g·cm^{-3}]	friction index i	theoretical density ρ_{th} [g·cm^{-3}]	apparent porosity* P_0 [%]
A	3.01	3.9	1.2838	7.6432	60.62
B	2.96	3.5	1.1875	7.6432	61.27
C	2.86	3.6	1.2587	7.8381	63.51

* $P_0 = (1-\rho_a/\rho_{th})\cdot 100\%$

where:
ρ_a - apparent density
ρ_t - tap density
i - friction index
ρ_{th} - theoretical density,
P_0 - apparent porosity,

Using linear regression there were calculated compressibility parameters K, n, and correlation coefficient r.

Parameters are presented in Table 3.

Tab.3. Calculated value of compressibility parameters K and n, fictive pressure p_1 and correlation coefficient r.

Material	$K \cdot 10^{-2}$	n	p_1 [MPa]	r
A	1.79	0.7304	359	0.9983
B	1.88	0.7182	341	0.9912
C	1.19	0.7795	542	0.9999

According to data listed in Table 2 and 3, the carbon coating of Astaloy CrL influences the parameter n which is lower than for powder systems based on the carbon admixing. System B (n = 0.7182) shows an higher ability to plastically deform than system A (n = 0.7304). The value for different powders is ranging from 0.5 to 1 [1-3]. In the case of powders with high plasticity, n is close to 0.5; in the case of low plasticity, n is close to 1. The effect of powder morphology also is reflected in the values of parameter K, which is the lowest for powder C ($K = 1.19 \cdot 10^{-2}$) and increases with the carbon addition to powder (system B, $K = 1.88 \cdot 10^{-2}$). The difference between powder A and B is connected with the different processing method and with the effect of particle geometry. Particle geometry is connected with the morphological properties, represented by the Hausner ratio [10]. Figures 1a-c show that the fitting experimental data and calculated data are higher up to 0.99.

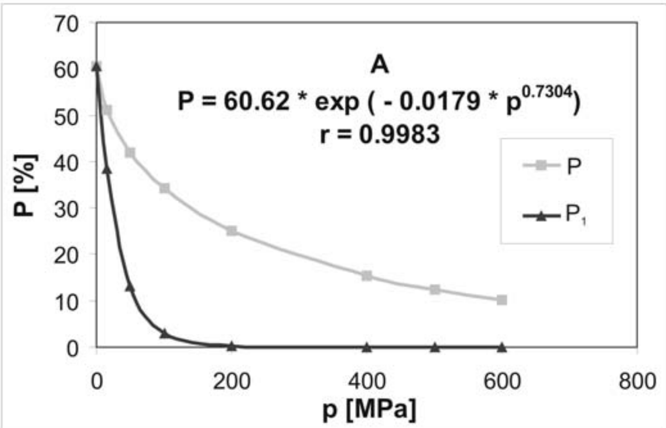

Fig.1a. Compaction curves of the A powder.

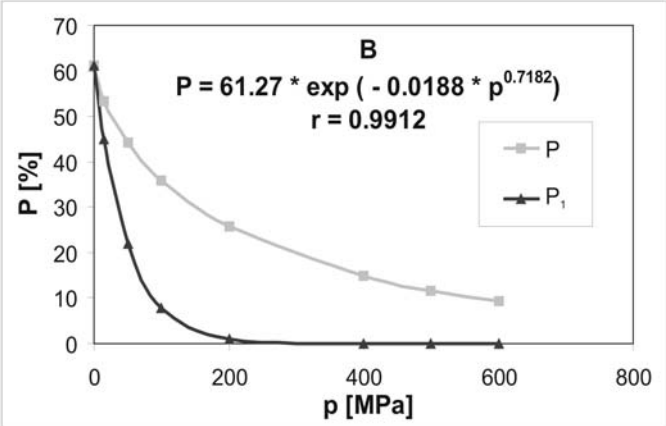

Fig.1b. Compaction curves of the B powder.

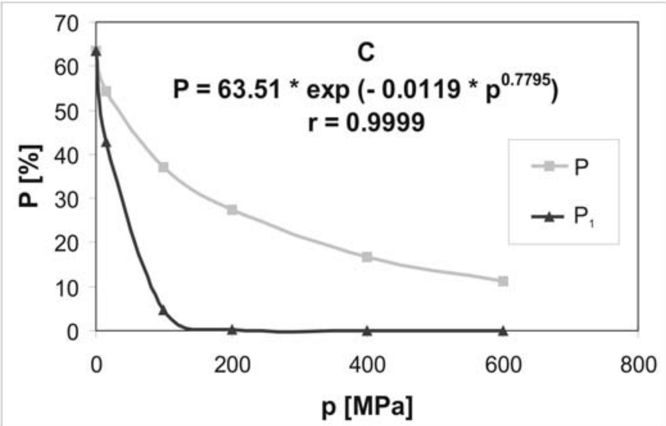

Fig.1c. Compaction curves of the C powder.

P_1 represents the "work" related to the densification done by particles transient rearrangement (for n=1). Compressibility of the admixed powder A is slightly lower than that of the coated system B, mainly in the area of pressing pressures from 50 to 400 MPa.

The compressibility equation (1) enables one to calculate the pressure p_1 needed for achieving an almost close to zero porosity, only by particle movements; in other words p_1 could be the minimal pressures needed to sufficiently strengthen the green compact. The results show a shifting from 542 MPa (system C, Astaloy CrL) to 359 and 341 MPa, respectively for the admixed and coated systems. Graphite has a generally positive effect on particle movement behavior [14,15]; carbon coating provides the best results in terms of particle rearrangement by translation and/or rotation of Astaloy CrL powders.

The presented equation (1) relates a powder consolidation state (such as porosity) to the compaction pressure. Equation (1) can be used for comparisons between different sets of data as well as for predicting the necessary pressure to obtain a required density. The analysis of the relationship among the values K_p and n_p with pressing pressure p, presented in Fig.2a,b, is useful for better understanding the effectiveness of the processing method on the compressibility of Astaloy CrL powders.

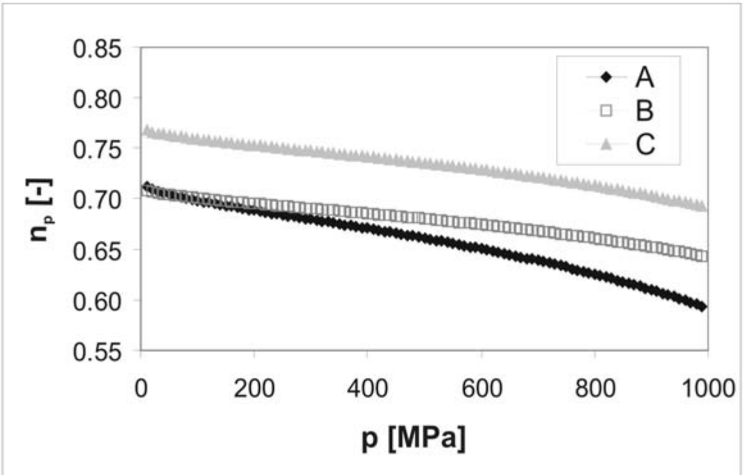

Fig.2a Dependence of n_p vs p.

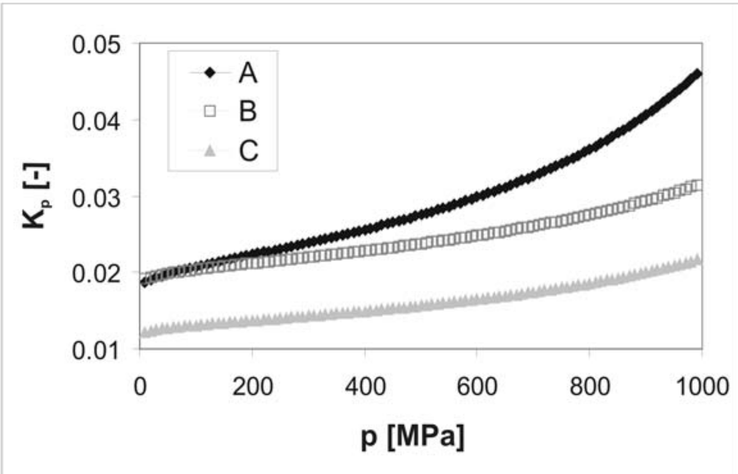

Fig.2b Dependence of K_p vs p.

Figure 2a expressed dependence of compressibility parameters n_p vs pressing pressure p. A value near to 0.5 expressed that given material has the best compressibility. Figure 2b presented dependence of compressibility parameters K_p vs pressing pressure p. The highest value expressed the best result for the compaction behaviour of material. The dependences of compressibility parameters n_p vs pressing pressure p and K_p vs p, respectively, revealed that the presence of carbon corresponding to increased compressibility behaviour of Astaloy CrL (mainly represented by results of system A). Finally, the dependences of compressibility parameters vs pressing pressure provide better information on compressibility behaviour.

CONCLUSION

Considering the densification of metal powders in a uniaxial compaction, the relationships of the values Kp and np with the pressing pressure p clearly show the influence of the processing method on compressibility by the tested Astaloy CrL. Comparing systems A and B, the particle movement seems to be a more effective mechanism in densification up to pressures ~ 400-500 MPa than at higher ones. The use of carbon coating determines a higher plasticity than carbon admixing and that the coating has a positive effect on the final densification behaviour of Astaloy CrL powders.

Acknowledgements

The authors are grateful to the Slovak Grant Agency VEGA 2/6209/26 for support of this work. R. Bidulský thanks the Politecnico di Torino and the Regione Piemonte for co-funding by fellowship.

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