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Powder Alloy Plasticization in Die Compaction

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Abstract: Plasticization behavior in metal alloy compaction is crucial because its gradient in compacted may promote premature breakages of the compacted under loading. In case of post-compaction process, this gradient may cause significative variation in densification, resulting in residual stresses. Therefore, the plasticization of the compacted powder of AlCoCrCuFeNi high-entropy alloy is presented in the context of a die assembly via the finite element method. The results are discussed in terms of the gradient of alloy powder mass plasticization. From the knowledge of the plasticization mapping of the compacted, different strategies of geometry and types of equipment can be proposed to improve the compaction process.

Keywords: Plasticization; Die; Powder compaction; Powder metallurgy; Alloy.

Plastificação de Pó de Liga em Matriz de Compactação

Resumo: O comportamento de plastificação na compactação de ligas metálicas é crucial, pois seu gradiente no compactado pode promover rupturas prematuras do material compactado sob carga. No caso de processos pós-compactação, esse gradiente pode causar variações significativas na densificação, resultando em tensões residuais. Portanto, a plastificação do pó compactado da liga de alta entropia AlCoCrCuFeNi é apresentada no contexto de um conjunto de matriz por meio do método de elementos finitos. Os resultados são discutidos em termos do gradiente de plastificação da massa do pó de liga. A partir do conhecimento do mapeamento da plastificação do material compactado, diferentes estratégias de geometria e tipos de equipamento podem ser propostas para aprimorar o processo de compactação.

Palavras-chave: Plastificação; Matriz; Compactação de pó; Metalurgia do pó; Liga.

Introduction

Raw alloy powder can be obtained via plasma rotating electrode process (PREP), mechanical milling/grinding, and electrode induction-melting gas atomization (EIGA) [1]. In the context of powder metallurgy, the alloy powder is often subjected to a compaction process to be agglomerated into a more defined geometry. However, the compacted part undergoes a post-compaction process very frequently due to its lack of resistance [2]. The heat treatments to which the compacted is frequently subjected aims at improving the mechanical properties,

metallurgical features, and geometric parameters, although other post-compaction processes are also performed [3].

In the stage of powder compaction, which is the scope of this paper, the tooling is considered rigid in view of the deformation of the powder. In cold axial compaction by punching, the powder is inserted into the die cavity and is pressed down by the lower surface of the punch against the internal surfaces of the die. In this context, the density depends on the following parameters: (a) lubrication between the parts of the die assembly; (b) compaction method; (c) friction; (d) dwell time; and (e) compaction pressure. The latter parameter is selected to be the main input variable related to the plasticization [4].

Objective

The main objective of this work is to obtain the plasticization of the compacted alloy powder via the finite element method, when pressing AlCoCrCuFeNi powder metal alloy [5].

Material and Methods

The plasticization was obtained by applying a pressure load over a single-punch against the powder. The die chamber and the base react to partly transfer, the energy to the powder mass. The plasticization simulation was conducted in Ansys®, in which the model dimensions and its boundary conditions, which are shown in Figure 1, are similar to those presented in [6]. Table 1 complements Figure 1 in providing dimensions and properties of the materials involved. As can be observed in Figure 1, the model addresses the lower surface of the base clamped, while the pressure is applied over the upper surface of the punch. The die chamber, the punch, and the base encapsulate the powder mass.

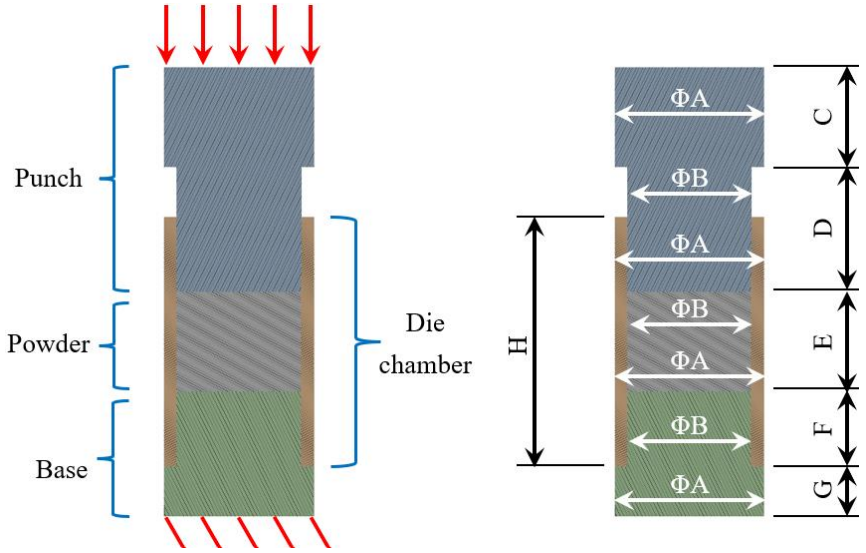

Figure 1. Boundary conditions and dimensions of the die assembly [6].

Table 1. Material properties and dimensions of the parts of the die assembly [7].

Part	Material	Elasticity modulus (GPa)	Poisson's ratio	Density (kg/m^3)	Yield strength (MPa)	Dimensions (mm)
Punch	AISI D2	207	0.28	7700	1500	A = 30; B = 25; C = 20; D = 25.
Base	AISI D2	207	0.28	7700	1500	A = 30; B = 25; F = 15; G = 10.
Die chamber	AISI D3	190	0.27	7860	2000	A = 30; B = 25; H = 50.
Powder	AlCoCrCuFeNi	207.5	0.3	3577	790	B = 25; E = 20.

It is important to note that the AlCoCrCuFeNi HEA was modeled with a porosity of 30% and an isotropic hardening characteristic, in which a tangent module of 72.3% of the elasticity modulus of the material was considered, i.e, 150 GPa [7].

Results

The results are presented in terms of the equivalent plastic strain plot in Figure 2. Based on this plot, the distribution of plasticity of the AlCoCrCuFeNi HEA can be seen as an increasing gradient in bottom-up and top-down directions, from the lower surface to the center, and from the upper surface to the center, respectively. Similar behavior is observed from the side surface towards the center part of the powder mass. It is important to note that the other components were not plasticized due to the design strategy based on selecting stronger materials to the die assembly when compared to the yield strength of the AlCoCrCuFeNi HEA.

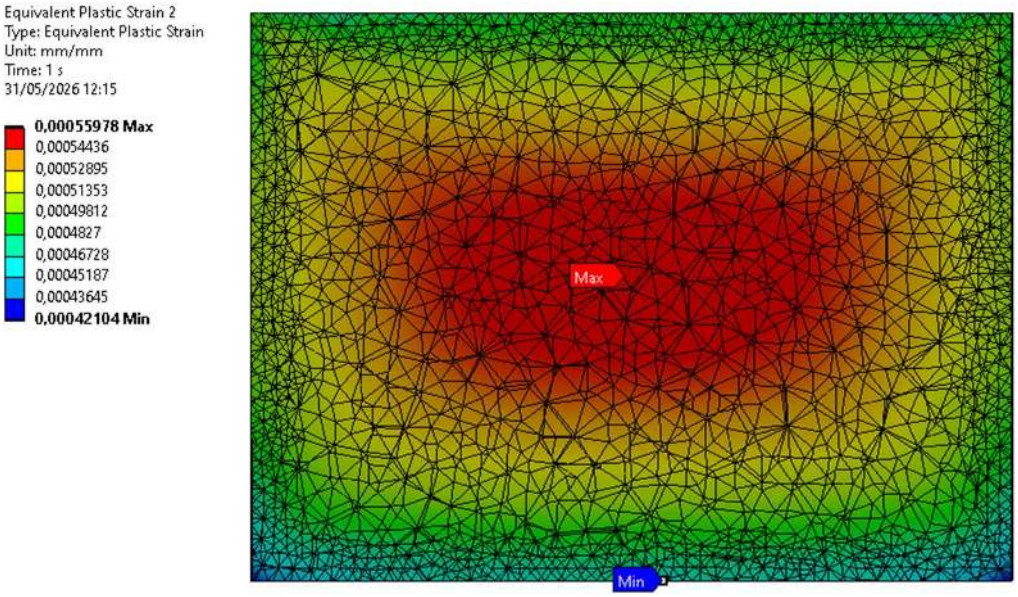

Figure 2. Equivalent plastic strain of AlCoCrCuFeNi alloy.

Discussion

To obtain the result of stress and plasticization, the applied pressure was 645 MPa, which corresponds to a von Mises stress of 1.092 GPa. In view of this, the applied load refers to 72.8% of the limit load of the less resistant components (punch and base, which magnitude of yield strength is 1.5 GPa).

The equivalent plastic strain distribution over the parts is in agreement to the expected, where the highest plastic strain (5.598×10^{-4}, indicated by the “max” tag in red color in Figure 2) appears in the upper and lower regions of the powder mass of AlCoCrCuFeNi HEA. This denotes that is the reason why the material of the punch should be more resistant than the material of the powder in the compaction process.

In what refers to the normal stress, Figure 3 shows its distribution along the profile section of the cylinder, where the section is such that the lower and upper lines represent the lower and upper diameters of the cylinder, respectively. The least critical regions are the leftmost and rightmost surfaces (-67.934 MPa), while the lower and upper surfaces present the highest levels (in magnitude) of normal stress (-123.290 MPa).

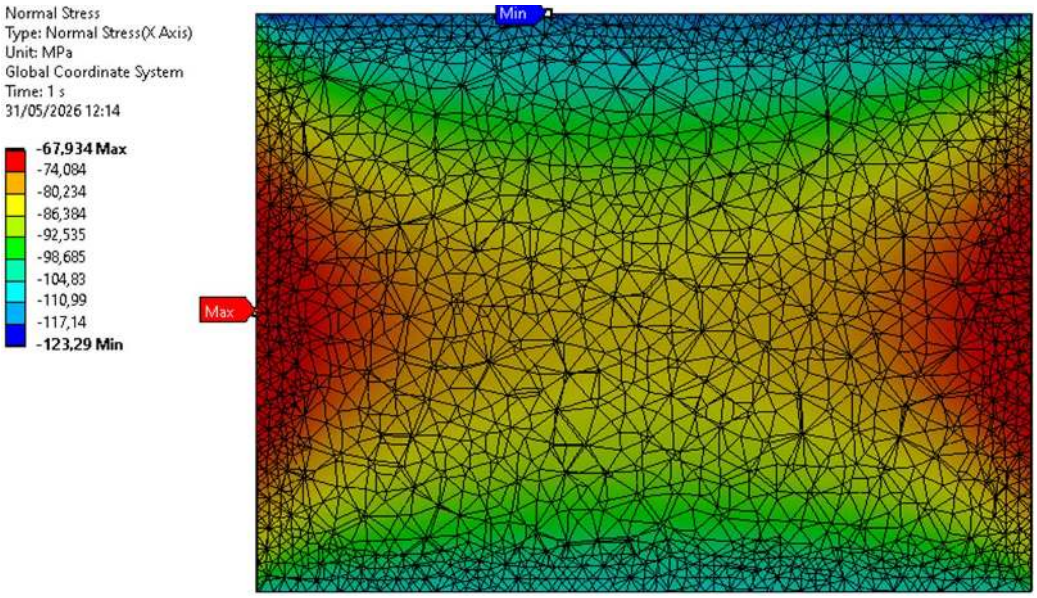

Figure 3. Normal stress of AlCoCrCuFeNi alloy.

In addition, the stresses at the corners could be reduced by chamfering or rounding, but this would imply that the geometric characteristics of the punch and base would be more prone to high stress levels due to the modifications demanded.

Regarding the results presented in Figure 2, two main improvements can be implemented to reduce the gradient of plastic strain in AlCoCrCuFeNi HEA powder mass:

(a) Height: if the height of the powder mass can be reduced, the plastic strain gradient will be more uniform. However, there is a physical limit to reduce this dimension due to a possible issue with the cohesion of the particles.

(b) Equipment: if, instead of a single-punch system, a double-punch system is selected, the gradient will be more uniform too.

Conclusions

The general objective of obtaining the plasticization distribution for the powder mass of AlCoCrCuFeNi HEA has been achieved. The central part of the compacted metal powder is less affected by equivalent plastic strain, while the upper and lower surfaces of the compacted were more affected.

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