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Influence of particle size ratio on densification behaviour of AISI H13/AISI M3:2 powder mixture

A. Fedrizzi [a,*], M. Pellizzari [a], M. Zadra [b]

[a] Department of Materials Engineering and Industrial Technologies, University of Trento, Via Mesiano 77, 38123 Trento, Italy
[b] K4Sint, Start-up of the University of Trento, Pergine Valsugana (TN), Italy

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ABSTRACT

The different densification kinetics of metal powders is one of the most important factors negatively affecting their possible co-sintering. This technological limit is further related to the relative fraction of the two powders, their shape and relative mean size. A decisive parameter, with this respect, is the so called particle size ratio defined as the ratio of the average particle size of the two powders. In this work the spark plasma co-sintering behaviour of an 80%vol AISI H13–20%vol AISI M3:2 blend is studied by considering nine different particle size ratios ($d_{H13}/d_{M3:2}$). The matrix of the relatively softer tool steel is strengthened by high speed steel. The highest values of density, hardness and fracture toughness are related to the smaller size of H13 particles (<45 μm), the influence of particle size ratio being not so relevant. For bigger H13 size (125, 250 μm), particle size ratios <1 promote a dispersion of isolated hard M3:2 particles, good densification and final high density. Increasing ratios evidence the formation of hard particles aggregates and a percolative network, respectively, which hinder densification. Above a critical value, however, the particle size ratio promotes densification in view of the lower "excluded volume" by smaller hard particles.

1. Introduction

In the last decades there has been a strong development of composite materials, like metal matrix composites (MMCs) which are based on metallic matrix reinforced with hard particles. These materials offer the possibility to combine the properties of the base components and also to tailor the properties depending on the specific application considered. In the case of tool steels, many studies propose to reinforce these alloys adding carbide particles (such as WC, TiC, NbC, Cr_3C_2) [1–6] or other hard particles (such as TiN, Al_2O_3, CrB_2) [1,2,4,7].

MMCs can be produced by powder metallurgy (PM). Since properties are mainly related to density, it is important to predict the densification behaviour during sintering. In general, densification strongly depends on the characteristic of the starting powder. German has considered the effect of particle size on both packing density and sintering shrinkage of bimodal powder mixtures with same chemical composition [8,9]. Powder blends with different particle sizes present increased packing density compared to monosized spherical powders since the addition of large particle to a small sized powder replaces porous regions between little particles with a dense material, and in the case of large sized powder the presence of small particles that fill the interstices also improves the packing density. German concluded that there is a specific composition of large and small particles which gives the maximum packing density, which means that wide particle distributions increase packing density. On the other hand narrow particle size distributions exhibit higher densification rate which leads to higher density after sintering, and this rate declines with the addition of large particles to a small particles matrix. Packing density and sintering shrinkage are adversely influenced by particle distribution width and both can predominate to determine the final density according to the sintering conditions.

Considering the MMC production by powder blending, the starting powder can be likened to a mixture of soft and hard particles, where the matrix alloy acts as the soft component and the reinforcement particles as the hard one. Regarding tool steel matrix composites the tool steel powder is the soft component, while the hard component can be a ceramic powder or a harder steel powder. Literature data about the densification of soft/hard mixture for different kinds of materials state that densification still depends on particle size but it is also strongly influenced by other factors such as the volume fraction of reinforcement [10–14], the ratio between soft and hard particle sizes [10,12,13] or the reinforcement shape [10,13].

Bouvard examined the densification behaviour under pressure of metal and ceramic powder mixture [10]. Hard ceramic particles are assumed to be non-deforming under the applied pressure, while soft metal particles are assumed to behave in a visco-plastic manner. According to the value of applied pressure, Bouvard proposed two main densification mechanisms. If the applied pressure is lower than the soft particle yield strength densification results from particle

* Corresponding author. Tel.: +39 0461 282402; fax: +39 0461 281977.
E-mail address: anna.fedrizzi@ing.unitn.it (A. Fedrizzi).

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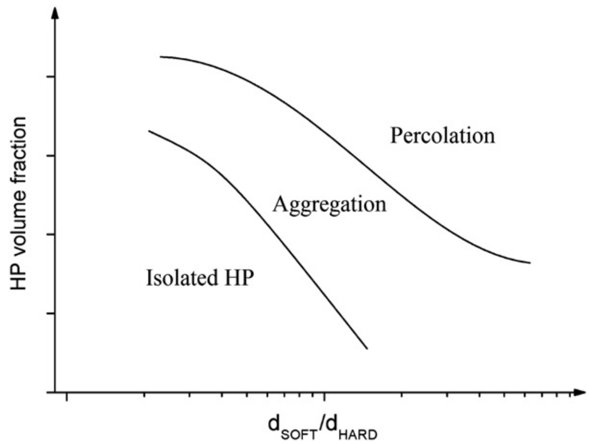

Fig. 1. Effect of hard particle volume fraction and particle size ratio on the densification behaviour of hard and soft powder mixtures.

rearrangement. This mechanism is strongly influenced by the particle size distribution and the particle shape and it is favoured by high fraction of hard particles. If the applied pressure increases, densification results from plastic- or viscous-deformation of soft particles. When applied pressure is high enough or the holding time is sufficiently long, particle deformation can lead to full density but the presence of hard particle generally hinders the densification. In this situation, according to the fraction of hard particle Bouvard distinguished three cases. If the hard particle fraction is low, then hard particles are well dispersed and, depending on sintering condition, soft particles can deform to fill all the gaps and complete densification can be reached. For a medium content of hard particles, these reinforcing particles form aggregates. The pores that Lange [11] called "excluded volume" in the middle of these aggregates are difficult to be filled by deformed soft particles and so their presence reduces the relative density of sintered compound. When the volume fraction of hard particles is high, hard particles form a continuous net, called percolate, which supports part of the external load. In this case plastic deformation of soft particles is difficult and rearrangement of the hard particle skeleton is also required to achieve high density. As it is schematically shown in Fig. 1, the hard particle fractions which define the densification behaviour of mixtures depend on the particle size ratio, defined as the ratio of the mean diameter of soft particles on the mean diameter of hard particles (d_{SOFT}/d_{HARD}) [10,12]. Generally, as this ratio decreases densification rate increases and the maximum fraction of hard particle which allows densification by soft particle deformation increases. In other words when the size ratio is much lower than 1 hard particle dispersion and thus high density can be achieved even for higher fractions of hard particles. Jagota and Scherer [15] showed that the percolation threshold is also influenced by the hard particle contact. This means that if the physical and chemical bonds between hard particles are weak, these particles can easily slide one against the other allowing high densification even for high volume fraction of reinforcements. On the other hand, if at the beginning of sintering process strong bonds between hard particles are created, these result in the formation of a rigid structure which hinders densification and therefore the percolation threshold decreases. This phenomenon was also highlighted during co-sintering of a hot work-high speed steel blend [16]. Due to the faster kinetics, sintering of hot work tool steel occurs at lower temperature so that, as high speed steel densification should start it is hindered by the presence of a rigid hot work tool steel skeleton. Delie [13] analysed the effect of hard particle aspect ratio resulting that it is better to choose spherical hard particles with a low specific area, i.e. bigger size, to favour densification processes.

The addition of ceramic particles brings an improvement in hardness but compromises material toughness [1–4,6]. To reduce this effect it has been proposed to replace them with a less brittle material, such as hard steel [17,18].

The present study considers the possibility to produce a reinforced PM hot work tool steel (HWTS) adding a high speed steel (HSS) powder as reinforcement and sintering the powder mixtures by spark plasma sintering (SPS). The influence of the mixture composition on the material properties has been previously investigated by present authors [16,19] by changing the volume fraction of HSS from 20% to 80%. In this paper the effect of particle size ratio (d_{HWTS}/d_{HSS}) and average hard particle size (d_{HSS}) on the densification behaviour and on material properties of 80%vol HWTS–20%vol HSS blends is examined. Results are evaluated in view of the theory of Bouvard to verify if his model can be applied also to systems in which both components can be deformed under the sintering pressure.

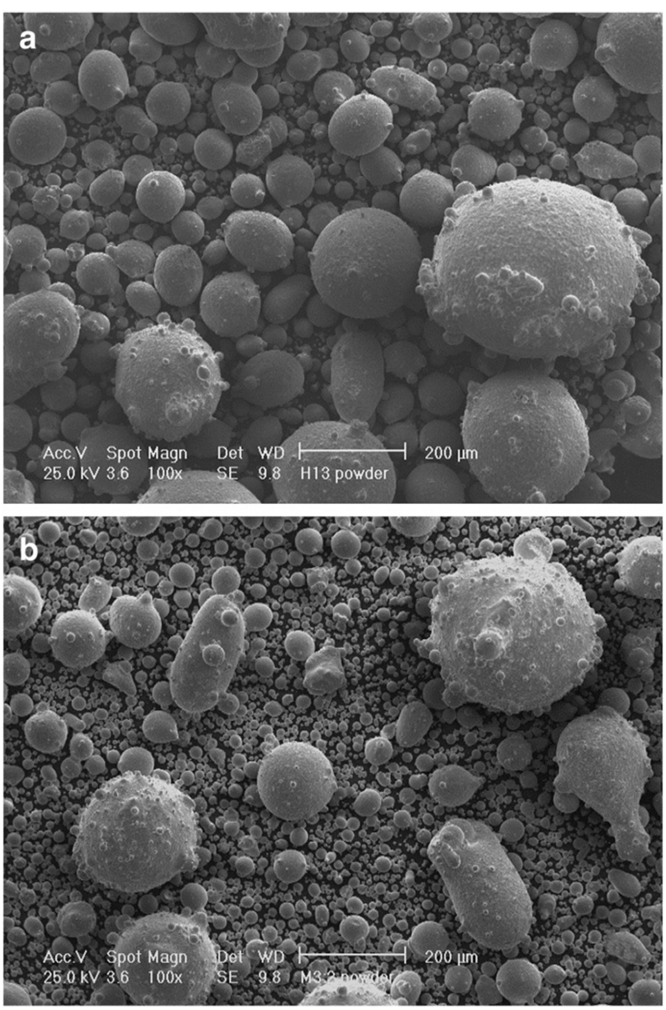

Fig. 2. SEM micrographs of unsieved powder of AISI H13 (a) and AISI M3:2 (b).

2. Experimental

The compositions of the HWTS (grade AISI H13) and HSS (grade AISI M3:2) powders used in this work are listed in Table 1.

Table 1
Nominal composition of the steel powders (weight %).

Material	C	W	Mo	Cr	V	Mn	Si	N	O
AISI H13	0.41	–	1.6	5.1	1.1	0.35	0.90	0.0383	0.0105
AISI M3:2	1.28	6.4	5.0	4.2	3.1			0.0559	0.0163