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TOWARDS THE FLOWABILITY AND SPREADABILITY OF CEMENTED CARBIDES AND CERMET POWDERS FOR ADDITIVE MANUFACTURING: EXPERIMENTAL AND NUMERICAL APPROACH – PART 1

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Abstract: *Powders processed by rotary electrode via plasma are perfectly spherical particles with smooth, fine and uniform surfaces and are the most requested for additive manufacturing, mainly for the PBF-L technique, due to their good flowability and the ease of providing a continuous flow in the powder bed. However, the cost of raw materials is very high and dependence on imports can become problematic situations in the product supply chain. Substituting irregular, cohesive powders with coarse textures results in poor flowability and interruption of powder flow in the ducts and powder bed. One of the major challenges for this work will be to analyze the dry flowability of WC and NbC refractory elements mixed with Co and Ni. For this, a container-type vibrating device was developed, with a capacity of 1.5 kg, coupled with a compacting roller that allowed to drain by gravity and vibration, ranging from 0.25 MPa to 0.35 MPa, for metallic sieves, with meshes varying between #35mesh (500 µm) and #50 mesh (300µm), and at the same time promote the compressibility of the mixtures in the powder bed. The survey of dry flow characteristic curves was obtained and the packing of these mixtures in the powder bed were analyzed.*

Keywords: *Metal powders, PBF-L, cemented carbides, cermets, flow curves.*

1. INTRODUCTION

The qualities of parts manufactured by Additive Manufacturing (AM) are influenced by the characteristics of the metallic powders, which include the shape, size distribution, surface morphology, composition and flowability or fluidity of the particles. Typical particulate sizes for sintering via Laser-Based Powder Bed of metals (L-PBF) are in the range of 10 to 60 µm. Scanning Electron Microscope (SEM), X-ray analysis and computed tomography microscopy techniques, among others, are often used to examine the shape and surface morphology of metallic particles. Laser diffraction and sieving method are used to ensure the size distribution of metallic powders and flowability is measured by Hall funnel flow meter (DebRoy *et al.;* 2018). The behaviour of a metallic powder is fundamental for its performance in the manufacturing process, such as conventional powder metallurgy, which in mold or matrix filling operations, powder spreading depends on flowability. Several methods or tests can help in assessing flowability, but it is not always clear to specify the best flow condition, with the different sizes and shapes that correlate (Marchetti, Hulme; 2021).

In the AM technique, an experimental characterization is very limited to measuring properties of metallic powders or parameters, such as mean diameter, particle size distribution and packing density; and it is inadequate to solve a specific configuration for powder bed deposition. Metal powders processed by Plasma Rotating Electrode Process (PREP) system, Fig. 1 (A), are perfectly spherical particles with smooth surfaces. Powder particles from the Rotary Atomization (RA) process, Fig.1(B), also have a smooth surface, but do not have a spherical shape. The Gas Atomization (GA) process, Fig.1(C) and (D), presents a spherical morphology and wavy surface texture, with the presence of small bound particles, called satellites, which increase the surface roughness. Powders produced by the Water Atomization process (WA), Fig.1(E) mostly have particulates with irregular shapes and coarse surface textures, resulting in lower flowability (DebRoy *et al.;* 2018).

For the direct sintering technique, via PBF-L, the behaviour of the metallic powder is a critical parameter. The powder flow for deposition is a complex phenomenon to understand or even to model and simulate. The properties of metallic powders are sensitive to external factors such as: relative humidity (%), geometric sizes and shapes or tensions applied between the particles. Other factors that also contribute to the deposition flow are the surface roughness and oxidation state, the apparent density and the electrostatic and magnetic characteristics of the material. This complexity has significant consequences on the flow from deposition to the powder bed, whether it flows or remains cohesive. If the powders are more cohesive than anticipated, this can limit the deposition flow and affect the quality of the final product. Therefore, an accurate description of the behaviour or feed flow of the powder for a specific process is of utmost importance (Marchetti, Hulme; 2021).

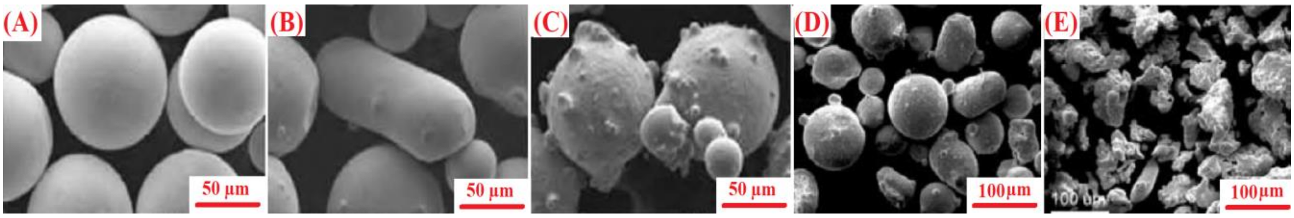

Figure 1 SEM images of metallic powders manufactured by the process (A) PREP (B) RA e (C) GA. Comparison of formats of powders manufactured by processes (D) GA; e (E) WA. (DebRoy *et al.,* 2018)

The powder metals used for AM are spread over a compacted layer for direct sintering and this process is repeated from layer to layer deposited, to form the product. Particle dispersion can be simulated using the discrete element method – 3D finite element modelling (DEM-FEM) to investigate the effects of particle shapes and operating conditions on the powder bed, consideration of surface roughness and fraction of solid volume (Haeri *et al.;* 2016).

The qualities of raw materials depend on their manufacturing process. The metallic powders produced by the WA process, in the additive manufacturing process, deposit thinner layers in the powder bed, when compared to the PREP, GA and RA processes. However, due to coarse surface textures and irregular shapes, mechanical components made from WA processing have high surface roughness. In contrast, PREP and WA exhibit more and less uniform particulate size distributions, which promote homogeneous fusion, good interconnection between particulates and a good surface finish. The metallic powders manufactured via PREP are considered high quality raw materials, as they have uniform sizes, smooth surfaces, fine sizes with good flowability and are capable of providing a continuous or uninterrupted flow in the nozzles or feed ducts, and for the powder bed. Components sintered via AM with this type of PREP powder have low porosity and high density. However, they are expensive metallic powders due to the high cost of the manufacturing process in relation to the yield of the atomization process (DebRoy *et al.;* 2018).

Marchetti and Hulme-Smith (2021), point out that the flowability of metallic powders can be evaluated by several measurement techniques and that they can be divided into separate categories, such as: flow rate, density rates (apparent or tapped), angle of rest, shear stress, among other methods. The difference between these methods can be important as a test method affects the stress state and velocity of the particulates, the bulk density, tapped density and packing density and other factors of the powder, influence the feed flow behaviour. These flowability methods for metallic powders have been known for a long time and are recommended for the PBF-L technique.

In most of these procedures, a funnel with different geometries is adopted and the best-known experimental configuration is the Hall flow meter (ASTM B213-17), which works well for non-cohesive powders, that is, more spherical. Metallic powder can flow due to gravity; it is a way to quantify mass flow. For a quantitative value of low flow, it means that it is a powder of good fluidity, this means that the friction between the particles is low. For the Carney Funnel (ASTM B964), it is recommended for cohesive powders, which have high frictional forces between irregular particles, the powder does not flow. For a good compressibility of a powder, flowability is a great indicator, as the particulates must move and settle on top of each other, to increase the density of the green compact (Marchetti; Hulme-Smith, 2021).

In general, the physical behaviour of metallic powders directly influences the parameters of the AM manufacturing process, via the PBF-L technique, the main properties are the shape of the particles, the distribution and size of the grains, apparent density, thickness of the deposited layers and the metallurgical properties of metallic powders (Pal; Drstvensek; Brajlih, 2018). Powder packing can be quantified from its apparent density. For this purpose, the flowability tests make it possible to obtain, from the apparent density (poured or aerated), the tapped density and compacted density. There are tests that promote a denser random packing, allowing the accumulated air (in the particulates) to leave, through agitation and settlement is done with a constant volume (Marchetti; Hulme-Smith, 2021).

The objective of this work is to present an individual method of flowability and spreadability for additive manufacturing technique, via PBF-L sintering; for fine irregular powders, coarse surface and high cohesion and to analyse the behaviour of the flow (mass flow rate), flowability (velocity) and density of powder mixtures of cemented carbides: WC-30Co, WC-30Ni and cermets: WC-30(Co ,Ni), NbC-30Co, NbC-30Ni and NbC-30(Co,Ni) with a high content of binder phase (30% by wt.), from the construction of a device - powder container, vibrator and coupled with a compactor roller to facilitate the spreadability of powder mixtures in the powder bed, via the PBF-L technique.

2. MATERIALS AND METHODOLOGY

The characteristics of the metallic powders, used in this work, are presented in Table 1. The chemical compositions of the cemented carbides, and cermets, based on refractories of NbC, WC and W, with metallic matrices of Co and Ni, presented in the Table 2. The powders come from the companies: WC, from Buffalo Tungsten Inc. (USA), electrolytic cobalt powder from Nanjing Hanrui Cobalt Co, carbonyl nickel powder from CVMR Corporation/Vale Inco Limited (International Nickel Company) and NbC from China from F&X Electro-Materials Limited.

Table 1. Properties of metallic powders and manufacturing route.

Powders (Symbol)	Theoretical Density (g/cm^3)	Average grain size (µm)	Purity (%)	Apparent density (g/cm^3)	Manufacturing Route
Tungsten Carbide (WC)	15.63	1.5	99.530	4.0	Hydrometallurgy and H_2 reduction and carburization
Niobium Carbide (NbC)	7.65	< 1.0	99.650	3.0	Direct reduction via carbothermic
Cobalt (Co)	8.91	2.0	99.970	2.0	Reduction and Precipitation (Electrolysis)
Nickel (Ni)	8.91	5.0	99.847	2.5	Carbonyl gas refining

The experimental procedure is initially based on the preparation of metallic powders, from conventional powder metallurgy techniques, and after the final control is on the characterization of metallic powders, which include SEM BSE test, apparent density and flowability of the powders. The theoretical densities of the alloys under study are presented in Table 2. The described values were obtained by expression (1). Example for the binary WC─30Ni e NbC─30Ni alloys (30% Ni, by weight) where: ρ_t: theoretical density, by; binding phase: 30% (weight percentage of Ni); carbide %: 70 (weight percentage of WC); $\rho_{carbide}$ = density of WC equivalent to 15.63 g/cm^3 and NbC 7.50 g/cm^3 equivalent to; ρ_{binder}= density of nickel (Ni) equivalent to 8.91 g/cm^3. Therefore, according to the rule of mixtures, by weight balance, the theoretical density is 12.75 g/cm^3 for the WC─30Ni alloy and for the NbC─30Ni alloy, it is equivalent to 8.005 g/cm^3.

$$\rho_t = \left[\frac{\rho_{binder} \text{ x } \rho_{carbide}}{\rho_{carbide} \text{ x (binder\%) } + \rho_{\text{binder}} \text{ x (carbide\%)}}\right].100\% \quad (1)$$

Table 2. chemical composition of mixtures via weight balance and densities.

Alloy / Designation		Weight Balance (%)				Density (g.cm^{-3})	
		Refractory ceramics		metallic			
		WC	NbC	Co	Ni	theoretical	Aparent
Cemented Carbides	WC-30Co	70.0	0.0	30.0	0.0	12.740	2.92 ± 0.07
	WC-30Ni	70.0	0.0	0.0	30.0	12.746	3.31 ± 0.07
	WC-30(Co, Ni)	70.0	0.0	15.0	15.0	12.743	2.90 ± 0.13
Cermets	NbC-30Co	3.0	67.0	30.0	0.0	8.003	2.01 ± 0.06
	NbC-30Ni	3.0	67.0	0.0	30.0	8.005	1.84 ± 0.04
	NbC-30(Co, Ni)	3.0	67.0	15.0	15.0	8.004	1.82 ± 0.06

2.1. Preparation of metallic powders

The metallic powders of WC, NbC, Co, Ni and combined Co/Ni, as defined in Table 2, were mixed and homogenized by a conventional stirrer with glass container Fig. 2(A), with a marine propeller, Fig. 2(B) for 3 hours using isopropyl alcohol as a lubricant, Fig. 2(C), at 3000 rpm, Fig. 2(D). The high-energy mill (Atritor or ball mill) was not used to avoid reducing the ceramic grains and kneading the metallic powders. After the mixing step, isopropyl alcohol was eliminated by means of conventional drying, in an oven at a temperature of 200°C for 2 hours.

2.2. The morphology of metallic powders

The particle shapes of metallic powder mixtures vary according to their manufacturing route, Table 1. Most metallic powders have particles with irregular shapes smaller than 10 µm, although we can observe powders with predominantly rounded and irregular particles with satellites for W and WC; for NbC, irregular polygonal particulates. For carbonyl Ni particulates, they have particles with dendritic and porous formats. For electrolytic cobalt, it is easily evidenced in Fig. 3 (B) and (C), the particulates are irregular in shape and the particles are aggregated. The particle shape of these mixtures,

Table 2, can be compared with the typical shapes of metallic powders manufactured for Additive Manufacturing (REP, RA, GA and WA), shown in Fig. 1. The observation of this property is evidenced by SEM microscopy (10 kx), BSE (backscattered electrons) in which Co and Ni particles (8.91 $g.cm^{-3}$) are darker in Fig. 3(A), (B) and (C) the lighter particles, WC particles (15.63 $g.cm^{-3}$) are highlighted due to density. For NbC particles (7.65 $g.cm^{-3}$), identification by contrast (light and dark gray) is difficult, as the densities are close to those of Co and Ni particles. For this reason, the identification should be made by the shape of the constituents and grain size.

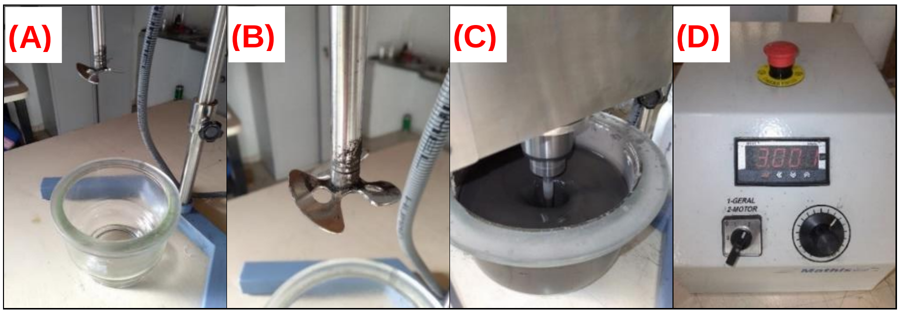

Figure 2 (A) Glass container with a maximum capacity of 5 kg of metallic powders, (B) propeller-type stirrer in maritime configuration for high density, (C) conventional homogenization and (D) propeller rotation variator.

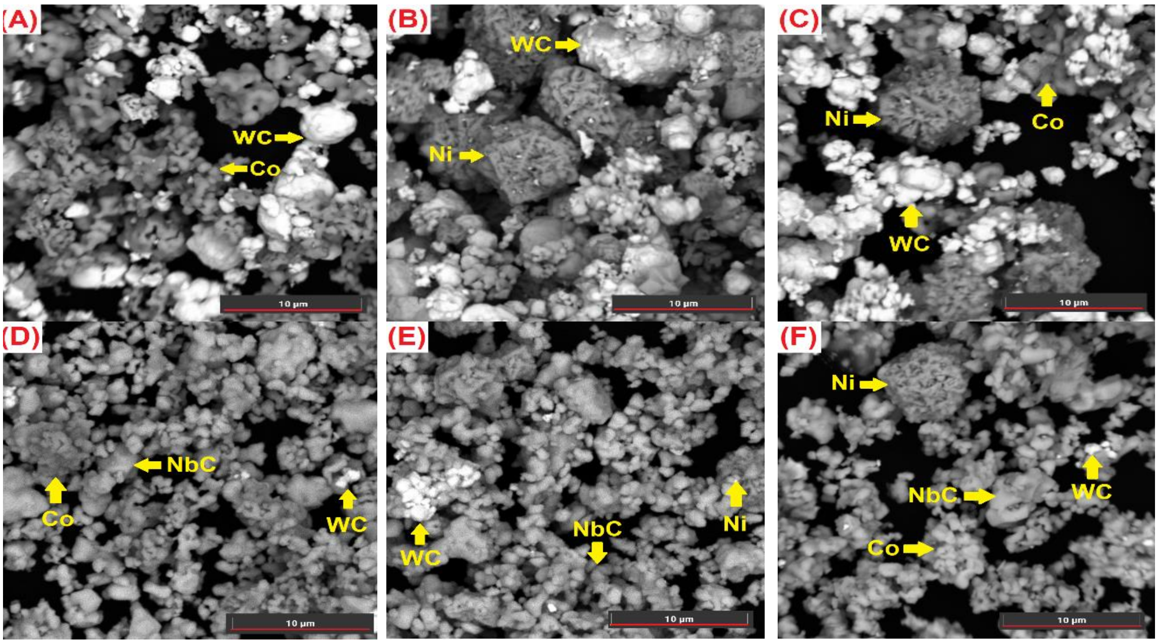

Figure 3. SEM BSE of mixtures: (A) WC-30Co, (B) WC-30Ni, (C) WC-30(Co, Ni), (D) NbC-30Co, (E) NbC-30Ni and (F) NbC-30(Co, Ni).

2.3. The construction of the device for flowability of high cohesion powders.

A vibrating-container type device was designed and built, coupled with a metallic roller, Fig. 4(A) and 4(B), whose rotation speed is controlled independently of its displacement speed. Compaction is carried out with a polished stainless steel metallic roller, inside the sintering chamber, in the powder bed, Fig. 4(C). The compressibility area of the powder mixture is very large (cross and longitudinal section); therefore, it is very difficult to deliver a high pressure, Fig. 4(D), when compared to the conventional powder metallurgy route. The compaction of thin layers with a roller compactor is interesting for extra fine metallic powders, for applications that focus only on three-dimensional printing, SLS, SLM, 3DP (Budding; Vaneker, 2013). In this compaction roller operation, the metallic powder needs to flow under the fluidizing container which is at the same time spread and compacted; and for this, it was necessary to select and determine a sieve, or stainless-steel mesh, to control the deposition flow of the powders of the prepared mixtures. Several methods can be adopted to determine the size and distribution of particulates. However, the most used is the sieving test with metallic fabric screens, which allows an adequate view of the granulometric distribution of the material, as well as separation into certain ranges, which must be designated by the nominal size of the openings in the metallic fabric, as shown in Table 3 (ISO NBR 3310, 2000).

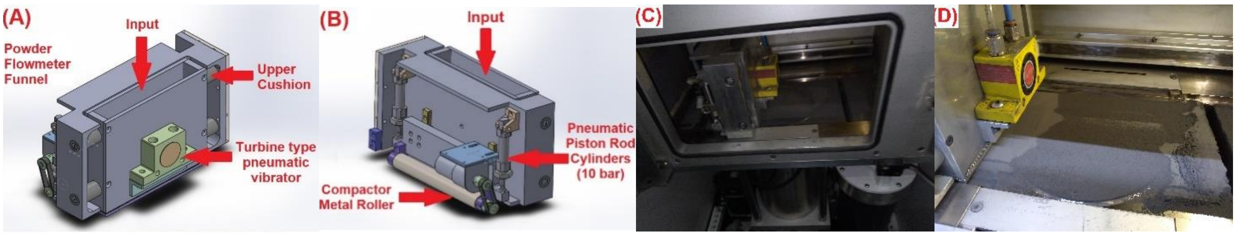

Figure 4. Isometric perspectives of the powder container and vibrating device coupled with a compactor roller, (B) sintering chamber, (A) Front View and (B) Rear View, (C) vibrating device installed inside the sintering chamber and (D) flowability and spreadability test of the powder mixes in the powder bed.

2.4. The choice of stainless-steel mesh for the vibrating device

The test apparatus involved a shaker and a set of standardized sieves, Fig. 5, and an analytical balance. A set of sieves was selected according to the characteristics of the powders analysed in the characterization via SEM BSE, which are the most common for mixtures of cemented carbides in manufacturing processes, which are the meshes: # 60, # 80, # 120, #140, #200, #230, #325, #400, Tyler-Mesh styled patterns. The organization of the sieves was done in descending order of openings. The amount of powder recommended by the standardized norm (ASTM B214) for this test is 100 g for materials with apparent density greater than 1.5 g.cm-3. However, they were tested for amounts of 200 and 1000 g, to analyse the empirical behaviour; therefore, the vibrating device built for the AM PBF-L technique has an experimental capacity of up to 1,500 g. It is recommended that the relative humidity of the air remain between the limits of 45% and 70% in accordance with international regulations for the use of instrumentation, mainly for measurement. The mixtures did not flow and agglomerated in the form of pellets, obstructing the openings of the stainless-steel mesh, as shown in Fig. 7(A), due to the relative humidity of the air, which greatly influenced the flow rate during the test. The mixtures were dried at 150°C in an oven for 1 hour. The test of granulometric distribution by sieves, Fig. 5, worked for 15 minutes, measured between 20 to 23°C.

This test was performed to define the best opening of the stainless-steel mesh (# mesh), for the vibrating container, shown in Fig. 6 (B), (C), (D) and (E). For the mixtures, described in Table 2, the granulometric distribution by sieving was expressed in percentage by mass of the test portion with precision of 0.1%. Analysing the Fig. 7(A) and (B), it is concluded that for the mixture tested with 200 g, meshes below # 100 (149 µm) are ideal. However, for the quantity of 1000 g, they revealed that the meshes must be below # 50 mesh (297 µm). After choosing mesh # 100 mesh (149 µm) for the first tests, the mixture powders did not flow, even with the device vibrating with the maximum pressure in the system (compressed air) of 0.4 MPa (520 Hz). With the #35 and #50 mesh, the mixtures flowed well and it was possible to carry out the tests, ranging from 0.2 MPa (400 Hz) to 0.35 MPa (520 Hz) in the system. Regarding the technical test procedure, a sample of 1,500 g was selected for each powder mixture. The internal part of the container has dimensions of 3.0x15.0x5.0 cm, Fig. 6(D). An analytical balance with a precision of 0.01 g was used, a plastic container to contain the escaped powder, a stainless-steel container was placed, Fig. 6 (B) for bulk density measurement. With this method it is possible to evaluate the flowability of fine powders, apparent density, tapped density and even the angle of repose, Fig. 6(D). The container for apparent density evaluation has internal dimensions of Ø 3.0x3.5 cm, with resulting volume in V= 25 ± 0.03 cm^3, based on ASTM B964. The values of fluxes and apparent densities of the mixtures are obtained from the average values of 10 measurements, with variations of less than 1% between the maximum and minimum values obtained. The apparent density is given by the expression:

$$\rho_{aparent} = \frac{Mass}{Volume} \quad (2)$$

The statistical distribution of sizes or granulometry of the mixtures, is usually expressed in the form of the relative frequency of the particles that were retained or evaded, for certain diameters, the curves of the cumulative fraction of particles that have a diameter smaller and larger than an average value of particle in a range of 0 to 100% are also used Fig. 6 (A) and (B). However, when there are different masses, when compared, the empirical behaviour is different. The classification of these solid particulates, both for 200 g and 1000 g, are considered ultrafine, according to the Tyler system, for 50 mesh (300µm) to 400 mesh (38 µm). The average diameter of the particles results from the knowledge of the size frequency distribution of the analysed mixtures, whose volume/surface ratio is the same for all particles present in the sampling during the sieving test, which is the average diameter of *Sauter*, expression (3), this average particulate diameter (Dps) is used in studies related to interfacial phenomena, particulate systems, mass transfer, kinetics and catalysis (Cremasco, 2009).

$$d_{ps} = \frac{1}{\sum_{i=1}^{n}\left(\frac{x_i}{D_i}\right)} \quad (3)$$

Fine solids			Ultrafine		
Tyler equivalent	Opening (Free)		Tyler equivalent	Opening (Free)	
Mesh	(μm)	(in)	Mesh	(μm)	(in)
3	6680	0,2630	50	297	0,0117
4	4699	0,1850	60	250	0,0098
6	3327	0,1310	70	210	0,0083
8	2362	0,0930	80	177	0,0070
10	2000	0,0787	100	149	0,0059
12	1680	0,0661	120	125	0,0049
14	1410	0,0555	140	105	0,0041
16	1190	0,0469	170	88	0,0035
18	1000	0,0394	200	74	0,0029
20	841	0,0331	230	63	0,0025
25	707	0,0278	270	53	0,0021
30	595	0,0234	325	44	0,0017
35	500	0,0197	400	37	0,0015
40	420	0,0165	500	25	0,0010
45	354	0,0139	600	15	0,0006

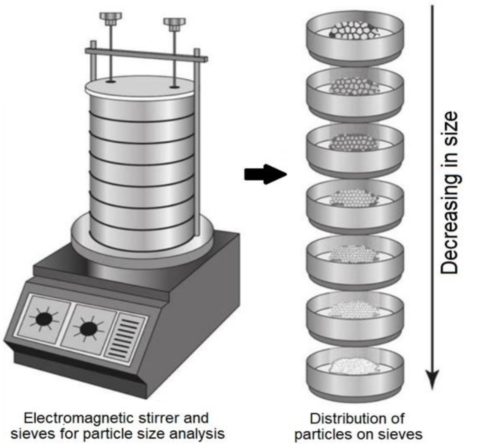

Figure 5. Classification of solids in accordance with the Tyler system. Adapted from Cremasco (2009).

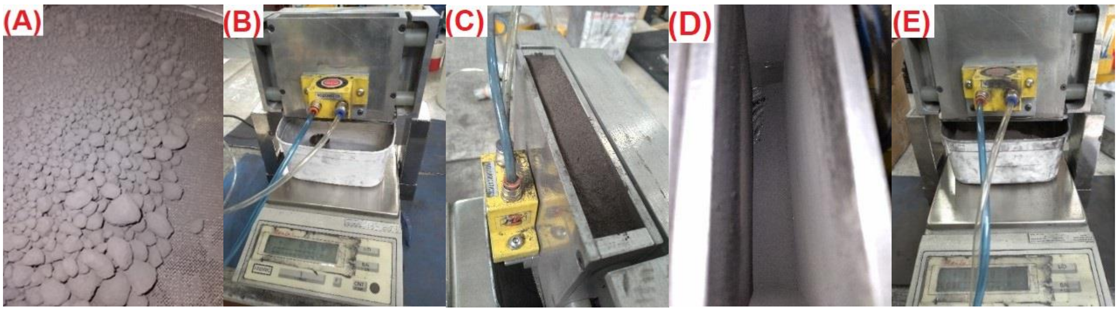

Figure 6 (A) Wet and agglomerated mixture in the stainless-steel mesh, making it difficult to flow. Fixing scheme for the device to evaluate powder flowability. (B) Installation of the vibrating container for the flowability test; (C) maximum filling of the mixture (1,500 g) in the vibrating container, (D) internal part of the vibrating container with the mesh of # 35 mesh (500 μm) and (E) obtaining the mass flow and apparent density.

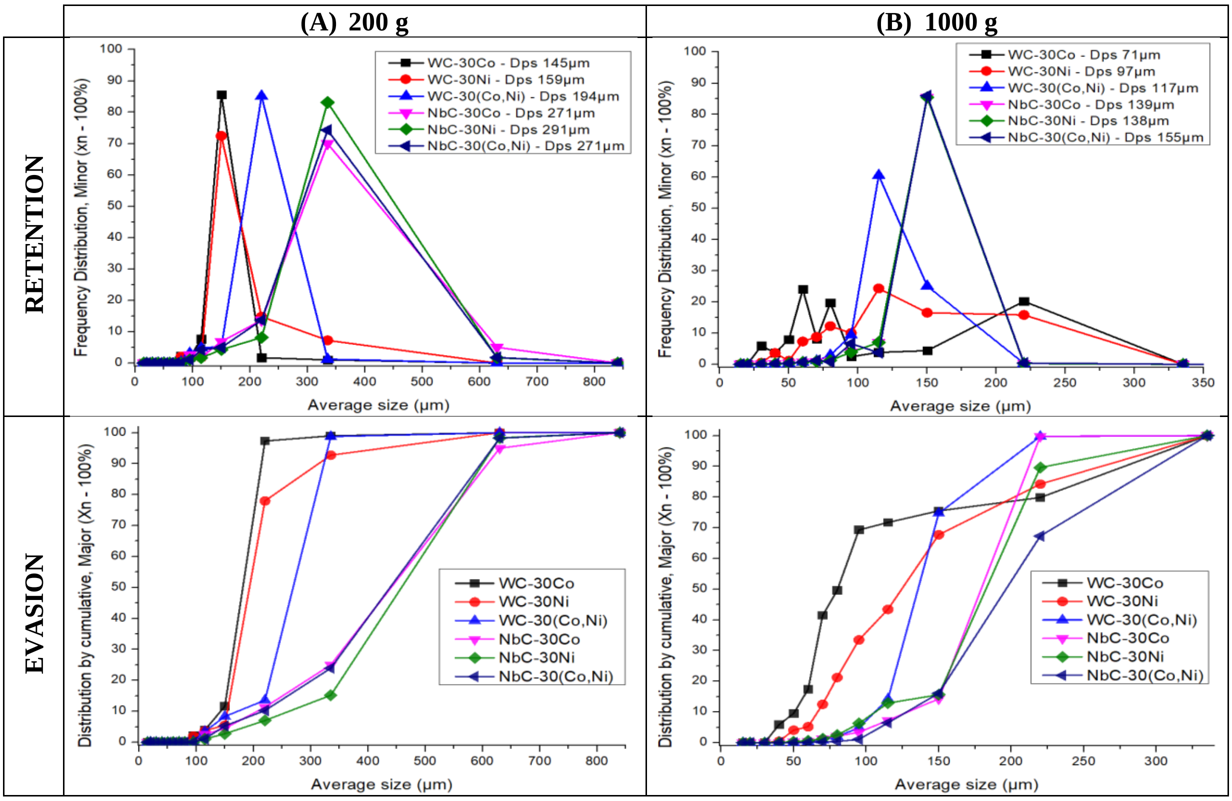

Figure 7. Particle size distribution, retention (Dps *Sauter*) and evasion test, for mixtures with (A) 200 g and (B) 1000 g.

3. RESULTS AND DISCUSSIONS

The flow test, powder mixtures, cemented carbides: WC-30Co, WC-30Ni, WC-30(Co, Ni), as shown in Fig. 8(A) to (F) and, NbC-30Co, NbC-30Ni, NbC-30(Co, Ni), for Fig. 9 (A) to (F), respectively, from the constructed device, is simulated and expressed in graphical form, relating to the mass flow as a function of time for mesh #35 mesh (500 µm) and #50 mesh (300 µm). For this new measurement methodology, ranging from 1,300 to 1,400 g of powder was placed in the container, in order to flow by gravity and by vibration of the device, varying from 0.25MPa (460 Hz), 0.30 MPa (490 Hz); and 0.35MPa (520 Hz).

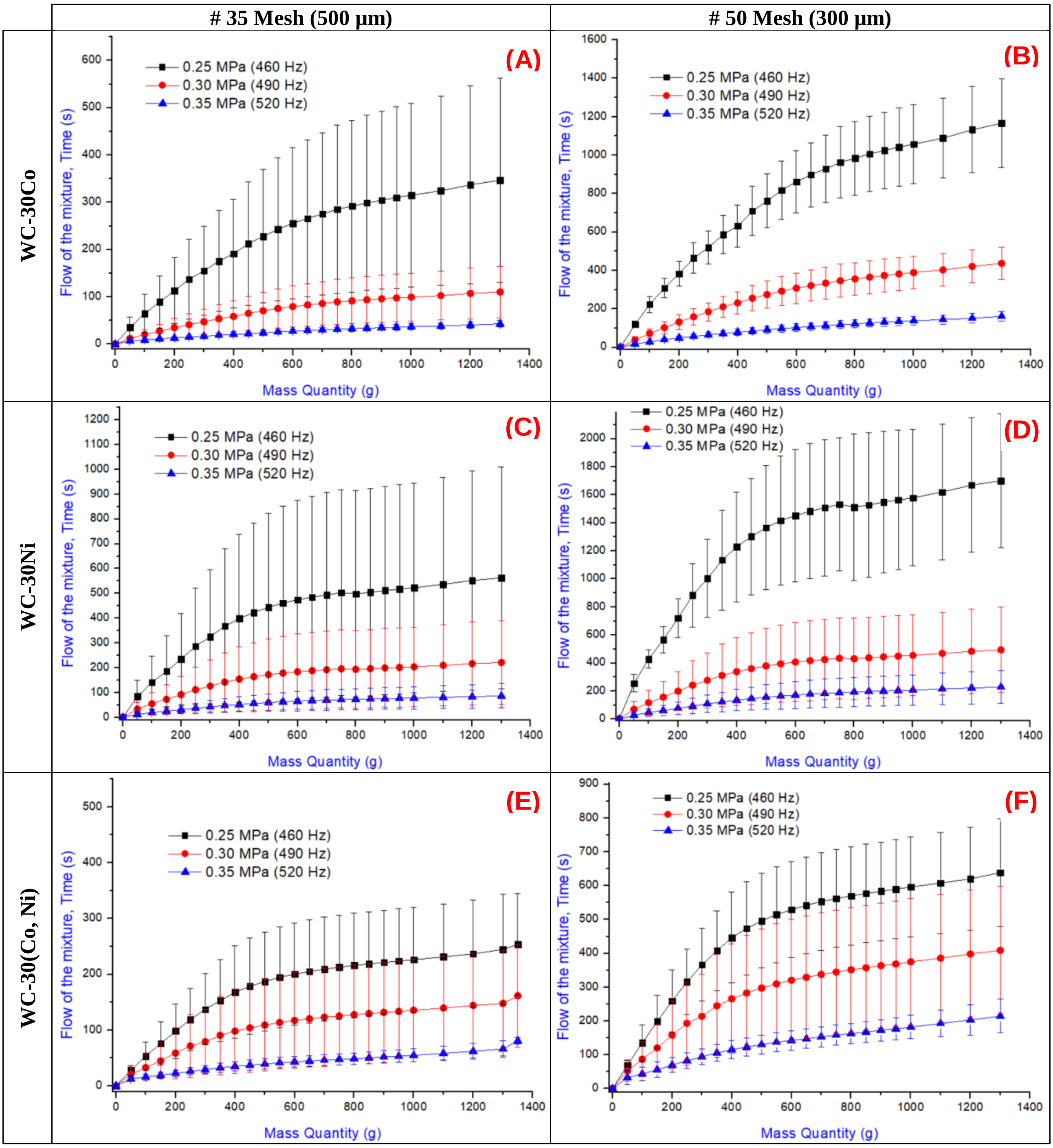

Figure 8. Mass flow of powder mixtures, for mesh # 35 mesh and for mesh # 50 mesh, depending on the pressure in the system or frequency of vibration of the container WC-30Co, WC-30Ni and WC-30(Co, Ni) alloy.

An important observation is that for values below 0.20 MPa, for #35 and #50 mesh sieves, the powder mixtures did not flow, the particles were packed (tapped density). And for a pressure of 0.40 MPa, the powder was expelled in large quantities from the top of the container. For the fluidity of cemented carbides mixtures, fluidity is not an inherent property, it depends not only on physical properties such as shape and size of particles, relative humidity of the air, others; in addition, should also consider the state of tension, and the handling method. The flow of powders in individual methods of additive technologies is a complex area of study (Zegzulka *et al.*, 2020). In the spreadability stage of the mixtures, in the powder bed, with the scraper ruler and the roller locked, the deposition layers, in the first preliminary tests, showed irregularities on the surface and lack of adhesion between the mixed particulates, Fig. 10 (A) and (B), for pressures from 0.20 to 0.25 MPa for # 35 mesh and # 50 mesh sieves.

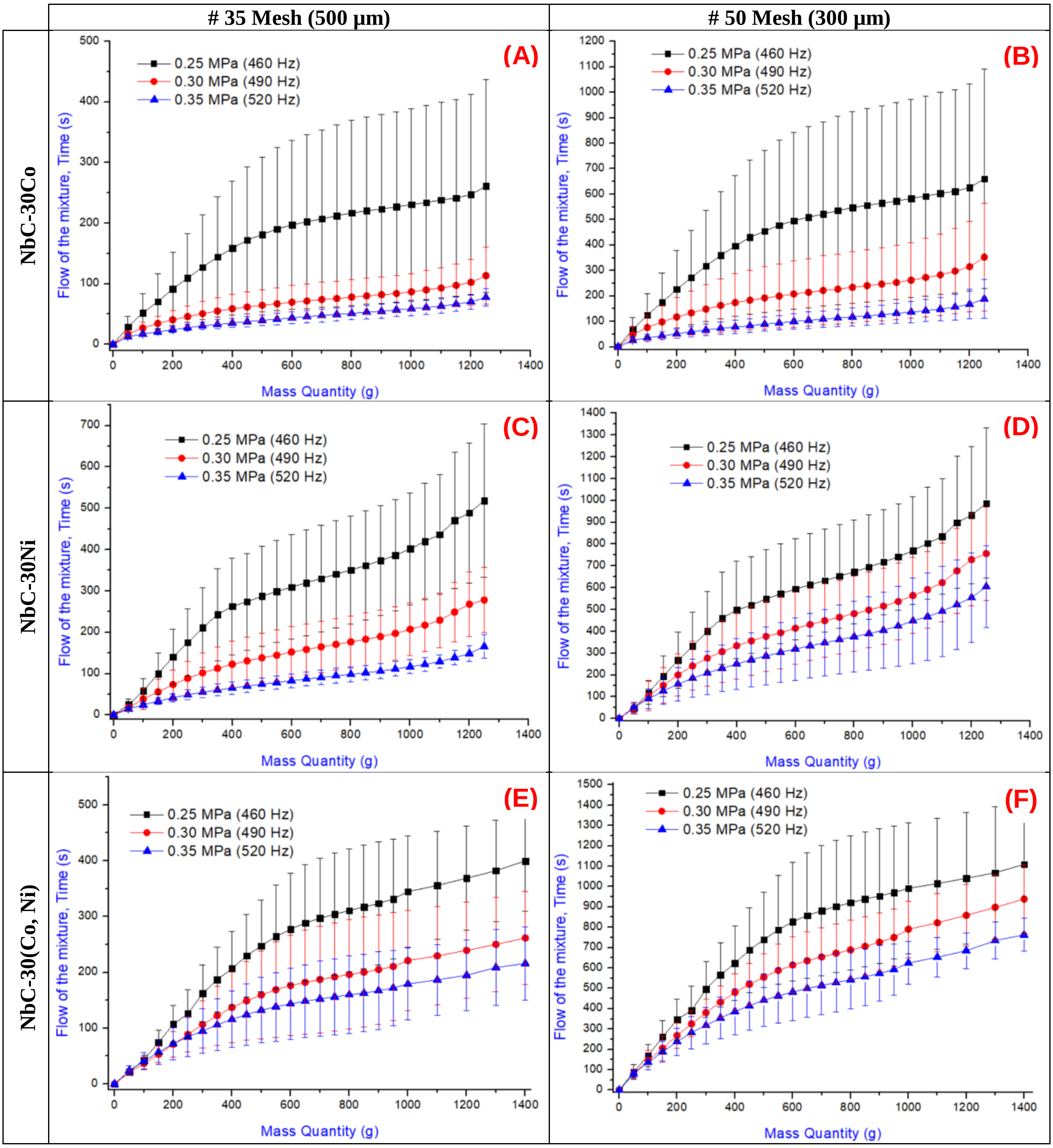

Figure 9. Mass flow of powder mixtures, for mesh # 35 mesh and for mesh # 50 mesh, depending on the pressure in the system or frequency of vibration of the container NbC-30Co, NbC-30Ni and NbC-30(Co,Ni) alloy.

For the pressure of 0.30 and 0.35 MPa, for both meshes, the sheets of the deposited layers were uniform and diffuse, for this reason the control of the mass flow versus flow time, for the control of the speed of the transfer of the vibrating device. In addition, there was a great improvement in densification, moving from a condition of apparent density to a tapped or pressed density, Fig. 10(C). For this reason, it was decided to keep the metal roller of the vibrating device locked for the direct sintering step and the best parameter was for a #35 mesh sieve and the pressure in the system for mixtures based on WC and NbC, respectively, 0.30 and 0.35 MPa. In Fig. 10 (D), the pressure in the system is 0.35 MPa, # 35 mesh, an excessive flow of powder and remains can be seen on the sides of the powder bed.

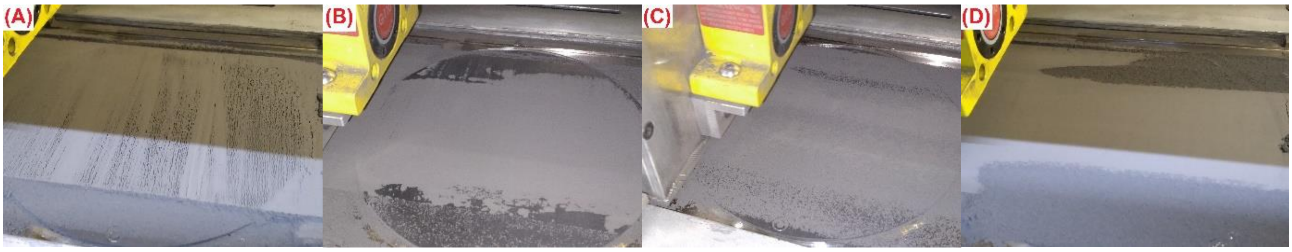

Figure 10. Behaviour of powder mixture spreadability, in the powder bed, as a function of system pressure or device vibration frequency (A) 0.20 MPa (400 Hz), (B) 0.25 MPa (460 Hz), (C) 0.30 MPa (490 Hz) and (D) 0.35MPa (520 Hz).

To achieve the ideal bulk and compact density, in the powder bed, the associated parameters such as linear and rotational speed of the roller, surface properties of the roller and thickness of the powder layer, must be carefully adjusted, this optimization process is complex, where the stresses applied to the powder layer are based on trial-and-error methods. Despite the simplicity of roller compaction, there are some unknown aspects of this technique from an analytical point of view. If using mathematical modelling and/or simulation, it will be possible to adjust the process parameters to better control the green density and porosity of the compacted product. The relative density (ρr) of the compacted powder layer is expressed by equation (3) (Shanjani; Toyserkani, 2008). The compaction process with metallic rollers, with dry granulation, is widely applied in the food and pharmaceutical industries; can continuously produce large quantities of compacted granular products at comparatively low cost. Two of the main advantages of this process are that it is dry and continuous. Despite being a simple process, a quantitative understanding has proven difficult to develop, due to the complex behaviour of particulate materials, which in the operational part of compaction can result in unsatisfactory linear compacts (Gururajan *et al.;* 2005). Another advantage is that for low pressures for thin layers (< 1 mm), in Fig. 11 (A) and (B), the dry bulk density.

$$\rho_r = \frac{bulk\ density\ of\ compacted\ powder}{powder\ material\ density}. \quad (3)$$

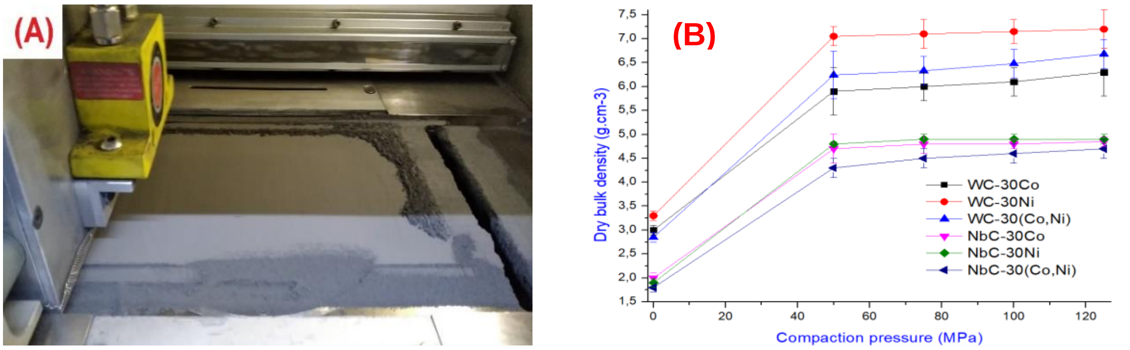

Figure 11 (A) mass flow rate of the vibration device with # 35 mesh (500 µm) of the WC-30Co mixture and (B) Effect of compaction pressure on the soil dry bulk density of the refractory mixtures.

It is intended ahead, exclusive and detailed studies regarding the study of the compaction behaviour, using the metallic roller, in the powder bed. The *Johanson* model (1965) is a simple measurement technique involving unidirectional compaction that investigates the particulate properties of the material, mainly dry, with respect to the compressibility factor, friction angle between the walls and can predict quantitatively, the performance of green compacted (Yusof; Smith; Briscoe, 2005). However, an experimental validation of the flowability curves of the mixtures, a more detailed simulation using a roller compactor to produce agglomerates, from dry fine particles, fed by gravity, has not yet been carried out, in the quantitative aspect (Gururajan *et al.;* 2005).

4. FINAL CONSIDERATIONS

This work is in progress, and the considerations so far are:

- The device developed in this work, using a vibrating container coupled with a compacting metallic roller, can be considered a new strategy for the flowability, spreadability and compressibility of mixtures of refractory and metallic powders, in particular, for mixtures of cemented carbides, in powder bed, for sintering techniques via Additive Manufacturing L-PBF.

- This method should only be used when the fine powders or powder blends do not have polymeric binders, or are not wet, and do not flow through conventional metering or dosing funnels.
- With this method it was possible to determine the mass flow rate, velocity or fluidity and apparent density of mixtures of cemented carbides and *cermets*, in a single test, for fine powders smaller than 10 µm.
- This new device has the purpose of filling layers in the powder bed, uniformly, without mass waste; which are related to the flow properties, which, therefore, influence the production rates and the uniformity of the compacted parts.
- The ability for WC-30Co, WC-30Ni, WC-30(Co, Ni), NbC-30Co, NbC-30Ni and NbC-30(Co, Ni) carbide powder mixtures to flow inside the vibrating device, is a function of the particle shapes (more irregular) and which increase the friction between the particles; the higher the friction, the lower the flow rate of powder mixtures in the powder bed.

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7. RESPONSIBILITY NOTICE

The authors are the only ones responsible for the information included in this work.