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Use of Inserts of Tool Steel with Solid Lubricant Aggregated made by Powder Metallurgy

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Abstract: This paper describes the making of insert of tool steel AISI H13 through the powder metallurgy process with the addition of solid lubricant in its composition. The experiment was done using molybdenum disulfide (MoS_2) to reduce the coefficient of friction of the insert. The lubricant added caused reduction in friction of the insert/piece system. Powder of solid lubricant was added to tool steel powder during the mixing step at concentrations ranging from 1 to 5%, and specimens were prepared for evaluation. The sample with 3% solid lubricant $MoS_2$was selected for development of the reported analyzes of low friction tribological systems when compared with systems obtained with tool steel manufactured by the conventional lamination.

Keywords : Self-lubricating, Sintered tool steel.

I. INTRODUCTION

Although desirable, the "perfect tribological" systems (zero friction) are virtually impossible to obtain, because there are many variables involved that affect its outcome, such as the tool material, the blank material, the lubricant, tool and blank temperature.

A technology that has emerged in the lubricants segment and has shown to be very effective is the solid lubrication [1]. Industrial sectors such as automotive, aerospace, petrochemical and durable consumer goods have interest in this technology, since they view the possibility of increasing the durability and reliability, as well as the quality and performance of components.

The solid lubricant has a wide application in the most used materials, and solid lubricants are: graphite, MoS_2, WS_2 and polytetrafluoroethylene (PTFE), being deposited on the surfaces that are in contact or added in the bulk concentration of the regions in touch [2-4]. The solid lubricants have low shear stress and high wear resistance because of its crystalline structure, and may also be applied as thin films on the surface or sprayed in powder form.

To enable an increasing of tool life can be incorporated solid lubricant in the volume of them or in the form of dispersed or precipitated particles of second phase. One way to accomplish this incorporating is by techniques of powder metallurgy (PM), more precisely in the mixing and sintering steps respectively, thereby generating a low friction coefficient - μ [5] composite.

In academic and industrial environments, the friction between bodies in contact is considered the main factor for the wear components [6-7]. Some consider that friction is a natural force, being the mechanism by which the forces of sliding surfaces develop resistance between two bodies in contact [8].

For them, the origin in shear strength is a type of friction force, which in turn comes from a process of "plowing" the hardest metal on the surface of ductile metal.

Some researchers show how the evolution of the sliding wear can lead to abrasion [9]. To this end, this model demonstrates that the hardening of the particles causes them to act as abrasives between the surfaces in contact, causing furrowing and crack nucleation in the region.

In 2006 the replacement of lubricants by solid film was made as a coating, giving less friction to the tribological system than if were working metal on metal only [10].

Although there are specific steels for cold forming, is very common in the industry that the tool steel is chosen by the user's feeling about dies and its performance in use. In many cases, the option for the use of steel is done in class "H", originally rated for hot work. One of these which steels commonly used is AISI H13 [11].

The tool steels have higher cost compared to conventional low-alloy steels. By choosing this type of material for the manufacture of forming tools is expected to get longer tool life to compensate this higher acquisition cost. The greatest resistance to wear, fatigue and fracture will help to dilute in higher production the cost difference of the raw material for the tool.

As seen in the literature, many authors have described studies on the use of MoS_2 as an alternative for solid lubrication, which can be seen in the group "B" (Fig. 1) exposed by Ludema [12-13].

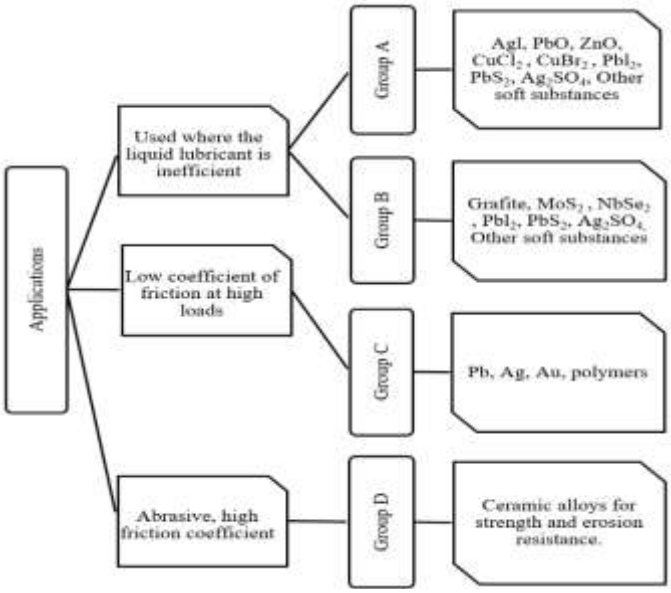

Figure 1. Functional groups of solid lubricants [13].

The tribological characteristics of lubricating films of graphite and molybdenum disulfide are very similar. This is partly because of the considerable similarity in the crystal structure. The layers of molybdenum disulfide are quite flexible and can slide one over the other repeatedly without damage [14].

II. MATERIALS AND METHODS

For this study was used as reference the steel powder for hot working selected in Class "H" and were added particles of solid lubricant to it by conventional processes of powder metallurgy. With the addition of this lubricant has the objective of reducing the wear of tooling.

Therefore, it was decided to work the characteristics of the compression process and sintering for hot work tool steel AISI H13 micro alloyed in composition with chrome-molybdenum-vanadium, hardenable in oil or air. It features excellent toughness, high mechanical strength and good wear resistance at elevated temperatures. Also shows good resistance to thermal fatigue, excellent resistance to thermal shock and heat softening. The tool steel powder was obtained by spray drying process with an average particle size less than 45 µm. Was added to the AISI H13 percentages from 1 to 5% molybdenum disulphide solid lubricant (MoS_2).

To perform the compaction of the specimens it was used a set of AISI D6 tooling steel (Fig. 2).

Figure 2. Compression dies for the specimens.

The compressibility curve showed the logged data (Fig. 3) when compressed at pressures from 100 to 1000 MPa. It is noteworthy that for the compression of the steel AISI H13 without adding lubricant powder, the samples were submitted to compressions only up to 800 MPa, because at higher pressures showed fracture green.

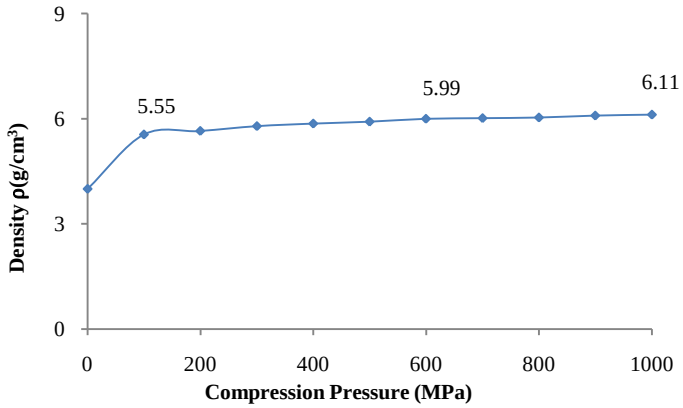

Figure 3. Green Compressibility curve H13 + 3% MoS_2.

The bulk density can be defined as the mass (g) of a unit volume of loose powder or the mass to volume ratio, expressed in g/cm^3. It is of fundamental importance to study this unit because it determines the required volume of powder in order to make a part with defined geometry, and consequently the course to be used in the press.

The bulk density values were obtained using the set of AISI D6 tool steel previously presented, in which the internal cavity has 50.0 mm in height (h) and a diameter of 13.0 mm. Filling it completely with the mixture of loose powder is obtained by a fixed volume of 6.63 cm^3, with cylindrical shape.

The masses of the compressed specimens were measured using an analytical balance, and by means of a micrometer, the diameter and height were measured to calculate the volumes. Using the equation of density that relates volume and weight, the green density of compact composites were obtained. The same procedure was performed for sintered samples; thereby the values of density of the samples in this condition were calculated.

For better characterization of the samples were carried out testing and evaluation of densities, linear and volumetric contractions, hardness and micro hardness, optical microscopy and scanning electron microscopy – MEV. Later tribological tests will be conducted to evaluate the friction conditions.

III. RESULTS AND DISCUSSION

The loads were mixed for 120 minutes to promote complete homogeneity. First was mixed 1% of MoS_2 to the H13 powder, adding more 1 wt% of each hour until there was a total of 5 wt% of the mixture.

Hundred cylinders were compacted (Fig. 4), of which fifty with graphite mixtures were not used in the first step. The other fifty samples, five variations of 1% to 5% MoS_2, were identified respectively with the letters "F" to "J". Each had ten different compression pressures from 100 MPa to 1000 MPa, called progressively with Roman numerals "I" to "X".

Were also compressed ten cylinder of AISI H13 tool steel powder with no added lubricant, which also appears in Fig.4.

Figure 4. Compressed specimens.

The powder mixtures were compacted thereby obtaining specimens for sintering. The green densities were calculated by dividing the respective mass (measured after each compression) by the corresponding

volume (obtained by measuring the height and diameter after each compression). Such amounts are shown in Fig. 5.

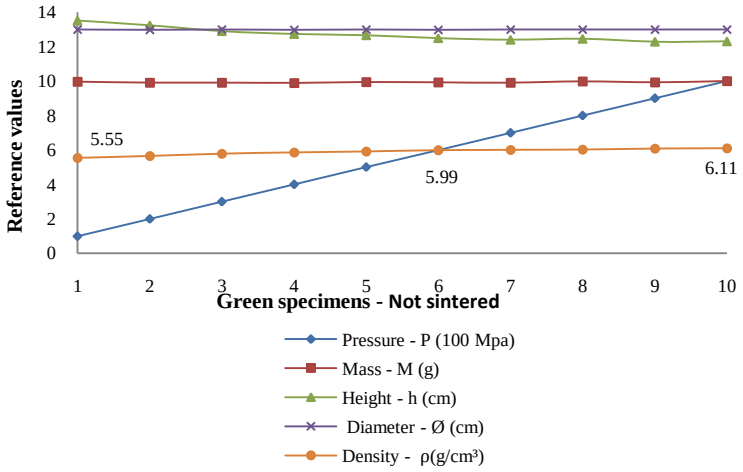

Figure 5. Values obtained from the green specimens.

It is observed (Fig. 5) that with 600 MPa pressure is obtained green density on the order of 5.99 g/cm³, which according to the literature is considered low for ferrous alloys. It was verified that tool steels with alloy elements such as Nb, Mo, Cr, and Ti (carbide) has a higher density than the density values obtained with the mixture of AISI H13 with MoS_2 [16-17] compressed to lower pressures.

It was decided to work with 1000 MPa compaction pressure, with which the samples showed green density higher than compacted parts with lower pressures.

The sintering was carried out in a continuous controlled atmosphere furnace at a temperature 1260 °C. The sintered specimens can be seen in Fig. 6. The identification of the right column is given by the letters "F" to "J", which in turn represent the percentage of 1% to 5% of MoS_2 added to the mixture with AISI H13 powder.

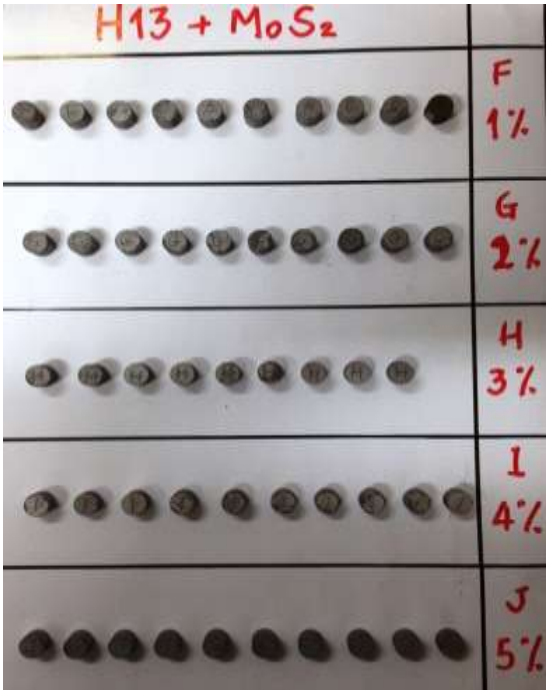

Figure 6. Sintered specimens.

After sintering was performed weighing each specimen using a balance with maximum 4,100 g, accuracy 0.01 g. Subsequently the samples were measured for height and diameter using a digital caliper. In possession of the data was generated a table of calculations that provided the density values of sintered parts. Fig. 7 shows the graph obtained with densities of sintered samples (H13 + 3% de MoS_2).

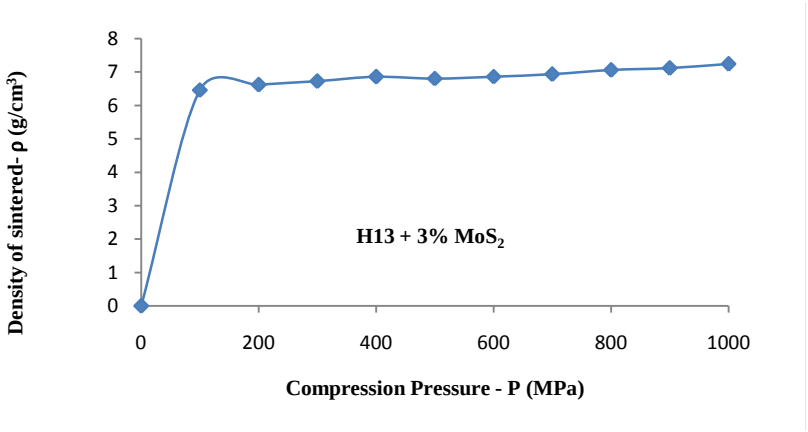

Figure 7. Density of the sintered specimens.

Table 1 shows the Vickers microhardness data obtained from specimens compressed with 300 MPa and after sintering.

Table 1. Involution of microhardness as a function of % of MoS_2 mixture - pressure 300 MPa.

Specimens with % MoS_2	Identification 300MPa (III)	HV Hardness periphery	HV Hardness central region	HV Hardness between center and periphery	Average HV Hardness
1%	F-III	673.44	623.48	598.55	631.82
2%	G-III	620.15	602.09	624.50	615.58
3%	H-III	593.21	583.75	641.00	605.99
4%	I-III	610.07	615.28	580.42	601.92
5%	J-III	411.43	475.32	458.28	448.34

It was observed that the hardness value obtained on the samples decreased with the increasing percentage of lubricant added to the mixture.

To avoid the use of little lubricant in the mixture by selecting the composition with only 1% MoS_2, and also not to use the mixture with marked microhardness fall as demonstrated in the sample with 5% MoS_2, it was decided to use the intermediate value of 3% to represent the defense of the intended concepts throughout this work.

Table 2 shows the Vickers microhardness data obtained on specimens compacted at 1000 MPa, and after sintering.

Table 2. Involution of microhardness as a function of % of MoS_2 mixture - pressure 1000 MPa.

Specimenswith % MoS_2	Identification 300MPa (III)	HV Hardness periphery	HV Hardness central region	HV Hardness between center and periphery	Average HV Hardness
1%	F-X	847.16	933.85	829.78	870.26
2%	G-X	723.57	767.28	690.92	727.26
3%	H-X	631.30	661.45	665.17	652.64
4%	I-X	667.77	644.27	590.02	634.02
5%	J-X	635.94	611.95	597.47	615.12

The variation in hardness in the parts compacted at 1000 MPa relative to 300 MPa was on the order of 7.5%. Converting these values to the hardness in HRC scale, the oscillation is between 56 and 58 HRC.

It can be observed in the analysis of Fig. 7 that there is little variation in the sintered density, considering the different compression pressures used.

For the continuity of the tests performed in this study, beyond the choice of the percentage of 3% of lubricant was also selected the pressure of 1000 MPa for compaction, because showed the highest density of the sintered composite. This is shown in Fig. 7 and is reinforced in Table 3.

Table 3. Densities of the sintered specimens.

Identification 3% MoS_2 (H)	Compression Pressure (Mpa)	Sintered Mass (g)	Sintered Volum (cm^3)	Sintered Density ρ (g/cm^3)
H-I	100	9.77	1,512	6.46
H-II	200	9.73	1,469	6.62
H-III	300	9.73	1,445	6.73
H-IV	400	9.75	1,420	6.86
H-V	500	9.77	1,435	6.81
H-VI	600	9.75	1,420	6.86
H-VII	700	9.75	1,406	6.93
H-VIII	800	9.82	1,390	7.06
H-IX	900	9.77	1,372	7.12
H-X	1000	9.84	1,359	7.24

The density value 7.24 g/cm³ of the specimen "H-X" is consistent with the literature data, which informs values between 6.7 and 7.3 g/cm^3 for Fe atomized powder sintered [17-18].

The aim of analyzes with the MEV was to demonstrate the presence of MoS_2 lubricants elements included in the AISI H13 ferritic matrix.

Fig. 8 is a magnification of 5000x of an area where can be visualized different phases of the mixing which were proposed to show. In detail are evidenced Area 1, a mixture of these phases, Point 2, predominantly MoS_2, and Point 3, predominantly of the AISI H13 ferritic matrix.

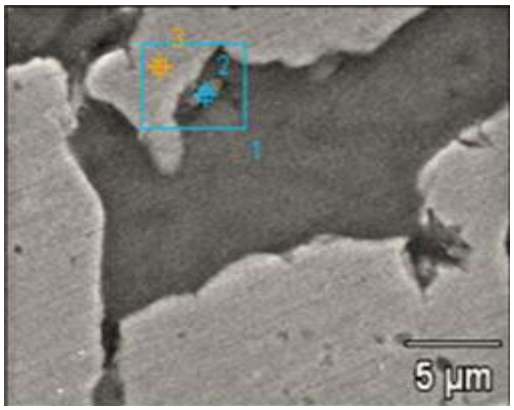

Figure 8. MEV - Image of Sample F-X - 5000x Magnification.

Fig. 9 shows the micro chemical composition of the rectangular area displayed in Fig. 8, comparative and quantitatively of chemical elements present respectively.

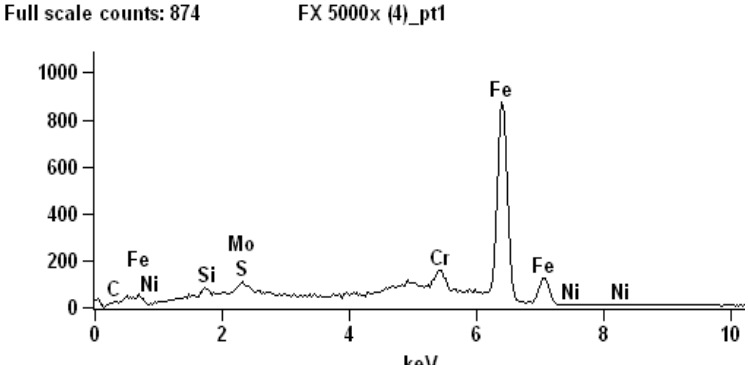

Figure 9. EDS Chart - micro constituents of Area 1 in Fig. 8.

Looking at Fig. e 9 corresponding to Area 1 EDS at a magnification of 5000 times that was shown in Fig.8, it is observed the presence of alloying elements in steel AISI H13 and MoS_2 compound is evident in the ferritic matrix.

Fig. 10 shows the EDS analysis of Point 2 showed in Fig. 8, also with 5000x magnification.

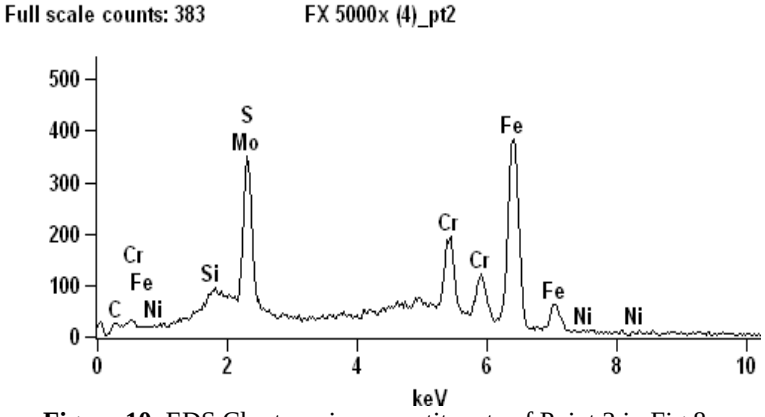

Figure 10. EDS Chart – micro constituents of Point 2 in Fig.8.

EDS analysis of Point 2 of Fig. 10 evidences the presence of MoS_2 compound, which may be called islands in the ferritic matrix. Such islands are scattered occupying the empty spaces between the microfusion of atomized tool steel powder.

Finally, Fig. 11 shows the EDS analysis of Point 3 in Fig. 8 with 5000x magnification.

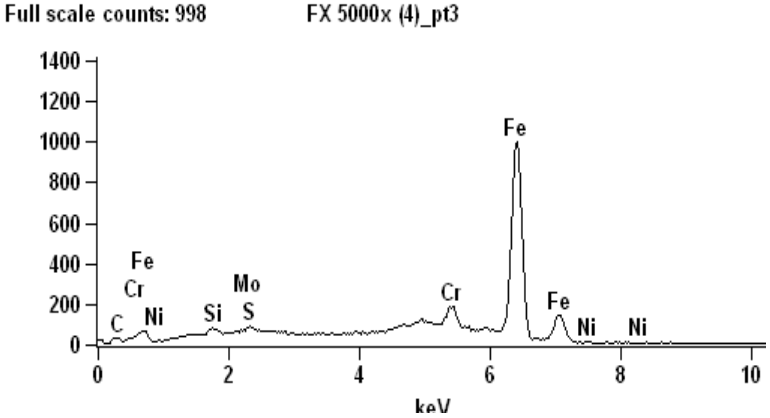

Figure 11. EDS Chart – micro constituents of Point 3 in Fig.8.

In Point 3 EDS graph with magnification 5000x there is a lower concentration of alloying elements and MoS_2 compound, being predominant the ferritic matrix.Part of the area 1 in Fig. 8 was 20000x magnified and is displayed in Fig. 12.

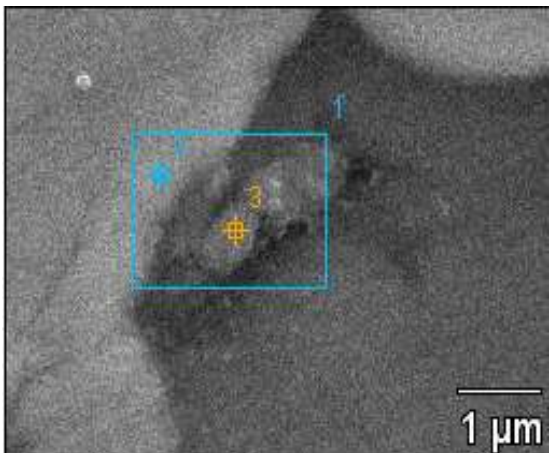

Figure 12. MEV – Image of F-X Sample - Amplification 20000x.

The exposed graph in Fig. 13 and Table 4 show the presence of MoS_2 lubricant in the ferritic matrix of tool steel AISI H13, confirming the scope of the primary purpose of carrying out the mixtures.

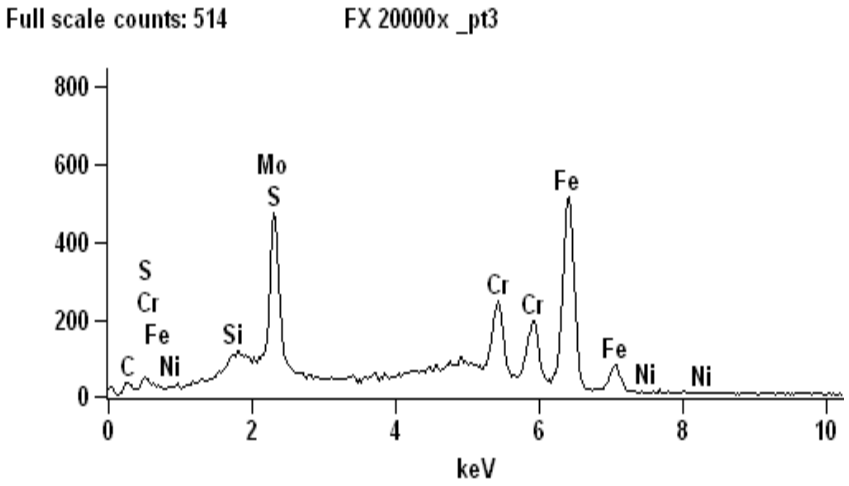

Figure 13. EDS Chart – micro constituents of Point 3 in Fig. 12.

Table 4. Micro chemical analysis (EDS) Sample F-X - magnification 20000x.

	C	***Si***	***S***	***Cr***	***Fe***	***Ni***	***Mo***
F-X 20000x _pt1	12.21	0.73	3.05	6.76	73.89	0.00	3.36
F-X 20000x _pt2	17.18	0.53	0.02	4.09	75.69	0.15	2.34
F-X 20000x _pt3	24.75	0.32	9.04	12.6	47.86	0.00	5.40

The statements herein characterized achieve the desired composite of tool steel AISI H13 with the addition of solid lubricant MoS_2.

The next steps are in place to verify the gains in lubrication and reducing friction through tribological tests.

IV. CONCLUSION

It is concluded that it is possible to use MoS_2 in conventional PM processes for obtaining self-lubricating materials.

The sintering temperature used showed no structural changes in the samples.

The percentage of MoS_2 influences the density of the sintered material, verifying that higher the percentage, lower the bulk density.

The percentage of MoS_2 influences the hardness of the sintered material, verifying that higher the percentage, lower the hardness.

The percentage of 3% MoS_2 chosen for the experiment showed satisfactory results both hardness and density.

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