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Compaction Behaviour of High Compressibility Low Alloy Steel Powders

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A B S T R A C T

Most popular low alloy steel powders contain nickel and molybdenum to increase hardenability. However, since Ni and Mo cause solid solution hardening of the iron matrix, the alloying of these elements may significantly reduce the compressibility of low alloy steel powders.

At Quebec Metal Powders, these metallurgical aspects were taken into consideration during the development of low alloy steel powders with the objective of optimizing both the compressibility and the heat treating properties. As a result, the manufacturing process of ATOMET 4201 and 4601 was successfully designed to produce low alloy powders exhibiting superior compressibility.

An investigation was conducted to study the effects of pressing parameters on compressibility of ATOMET 4201 and 4601 grades. Compacting properties of FL-4205 and FL-4605 mixes were measured and compared to those of a F-0005 mix based on ATOMET 1001 steel powder for different types and levels of lubricant and different loading rates.

INTRODUCTION

The compressibility of a metal powder is the capacity of the product to be compacted uniaxially in a closed die[1]. This basic property of any iron or steel powder has become increasingly important during recent years because of the need for higher density and higher strength required for high performance applications of P/M parts. Indeed, it has been well established that mechanical properties of sintered parts are directly related to the residual porosity, the higher the density, the higher the mechanical strength, elongation and toughness [2,3].

The compaction behaviour of a P/M powder grade is thus a critical parameter in achieving high performance properties. In conventional manufacturing of P/M parts, most of the densification takes place during compaction. Very little further densification, if any, takes place during sintering, unless very high sintering temperature or long sintering time is used.

Another method to increase mechanical strength of metal parts is to alloy the iron matrix with elements capable of improving the hardenability of the material. These alloying elements, although very efficient in increasing mechanical strength, may be detrimental to the compressibility. In fact, it is popular thinking in the P/M industry, that high compressibility can only be obtained with unalloyed iron powders or with diffusion-bonded powders whereas prealloyed powders exhibit low compressibility because of the solution hardening effect of the alloying elements.

Following the development of a water atomized super compressible steel powder grade, ATOMET 1001, Quebec Metal Powders proceeded to the development of two low alloy powder grades called ATOMET 4201 and 4601. These Ni-Mo alloyed powders were designed to combine both high compressibility and high hardenability. The purpose of this paper is to study the compaction behaviour of these low alloy powder grades and to quantify the relative effect of the main compaction parameters on the densification of pressed parts.

EXPERIMENTAL PROCEDURES

Compaction tests were done using three different grades of QMP's water atomized powders. These included two grades of low alloy steel powders, ATOMET 4201 and 4601, and a straight steel powder, ATOMET 1001. The chemical and physical characteristics of these powders are shown in Table 1. All powder properties are very similar except, of course, for content of alloying elements, namely Ni and Mo.

Each powder was blended with 0.5% graphite (SW 1651 grade) and lubricant, in proportion of 0.5%, 0.75% and 1.0% respectively. Both wax and zinc stearate were used as lubricant. For comparison purpose, a series of samples of each powder grade was also compacted using die wall lubrication. Powder blends were prepared in a 0.5 cubic foot twin shell blender.

Standard TRS bars of each powder mix were pressed at four different compacting pressures: 30, 40, 50 and 60 tsi. A double action die was used. All compressibility measurements were done in accordance with MPIF Standard 45. Each reported result is an average of three tests.

A first series of tests was conducted to verify the effect o the rate of pressure rise on the densification of low alloy stee powders. Three blends of ATOMET 4201 mixed with 0.5% graphite a 0.5%, 0.75% and 1.0% zinc stearate respectively were prepared an pressed at 30 tsi using four different rates of pressure rise, 1 30, 60 and 300 tsi/minute, as illustrated in Figure 1.

TABLE 1

Chemical and Physical Properties of ATOMET Powders

		ATOMET 1001	ATOMET 4201	ATOMET 4601
Chemical composition, weight %				
Carbon		0.003	0.004	0.003
Oxygen		0.08	0.10	0.08
Manganese		0.20	0.23	0.18
Nickel		0.07	0.42	1.79
Molybdenum		0.003	0.60	0.51
Physical properties				
Apparent density, g/cm^3		2.88	2.92	2.86
Flow, sec/50g		26	25	26
Screen size distribution, weight % (US mesh)				
+100	150	9.1	11.2	10.1
-100 +200	74	39.0	38.4	39.3
-200 +325	44	24.9	25.2	25.9
-325		27.0	25.2	24.7

In spite of the large range in loading rates used for these experiments, no significant difference was seen in the achieved densities of parts of the same mix composition. In fact, all green parts of a given composition exhibited densities well within a 0.01 g/cm^3 range. It was thus concluded that the rate of pressure rise does not significantly affect the final reading of compressibility. A compacting rate of 300 tsi per minute was used for all the other compressibility tests reported below.

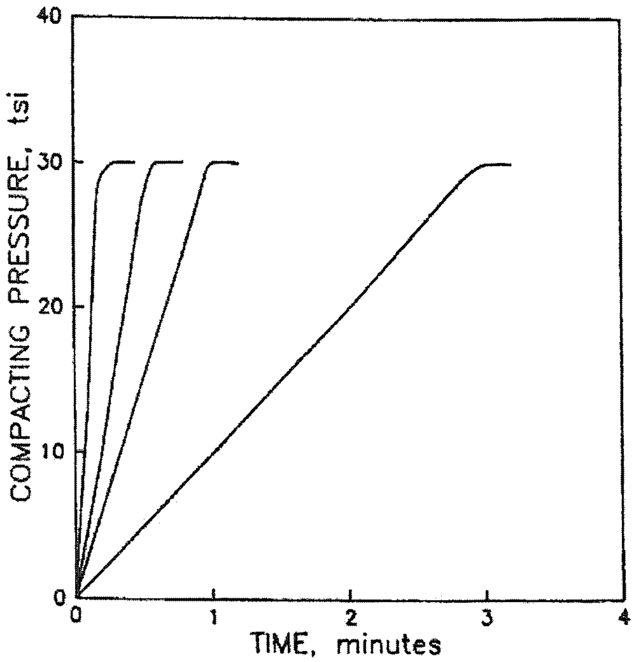


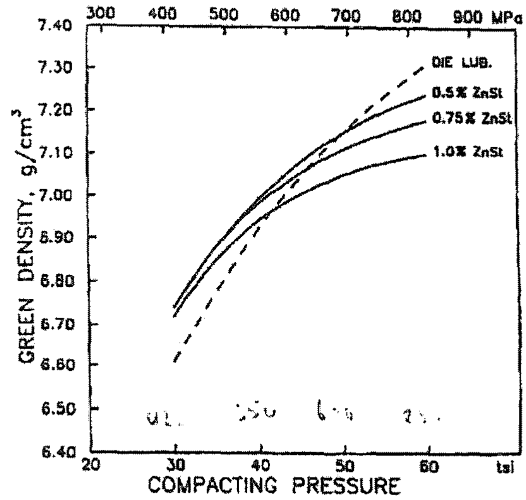
Figure 1: Experimental Compacting Rates: 10, 30, 60 and 300 tsi per minute.

COMPRESSIBILITY OF STEEL POWDERS

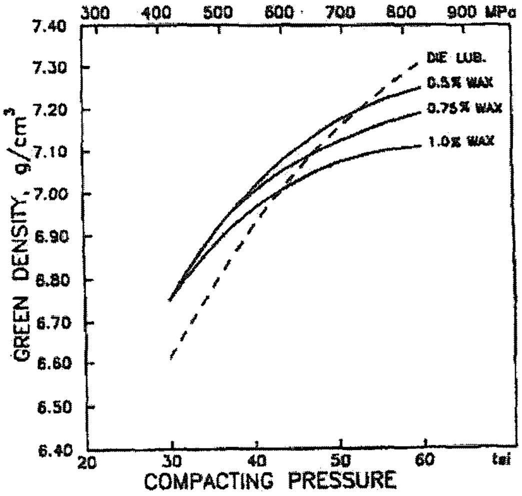
The compressibility curves of low alloy ATOMET 4201 and 4601 powders are shown in Figure 2a through 2d. The density-pressure relationship is given for both zinc stearate and wax lubricant additions. For comparison purposes, compressiblity curves of ATOMET 1001 straight steel powder are shown in Figure 3.

A striking characteristic of the new alloy powders is their behaviour as super compressible products. The achieved densities challenge the perception that prealloyed powders are generally seen as non-compressible products. As a reference point, 6.8 g/cm^3 is generally considered a lower limit for high density P/M applications. It can be seen in Figure 2 that a density of 6.8 g/cm^3 can be reached with compacting pressures of 32 tsi and 36 tsi for ATOMET 4201 and 4601 respectively. Densities of 7.0 g/cm^3 are readily achievable with compacting pressures as low as 40 tsi for ATOMET 4201 and 45 tsi for ATOMET 4601. Even densities in the order of 7.2 g/cm^3 are achievable under conventional single pressing practices.

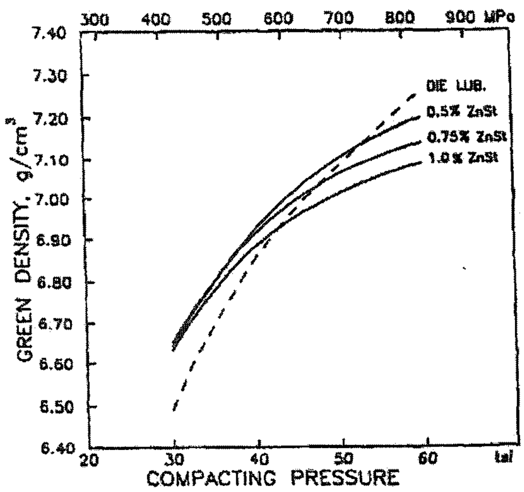
Figure 2 also indicates that the compacting behaviour of low alloy steel powders is affected by the concentration of alloying elements, as well as by the nature and addition level of lubricant.



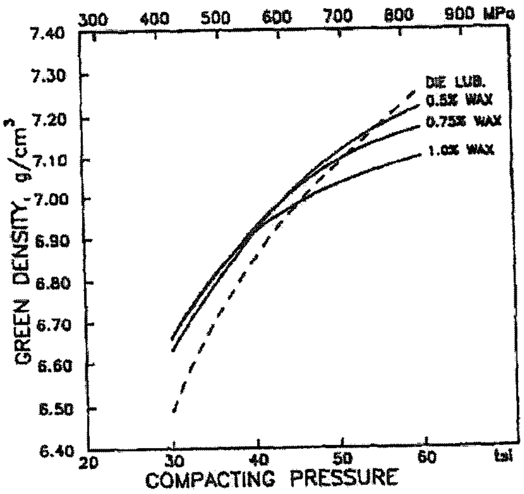
a) ATOMET 4201 + ZnSt (FL-4205)



b) ATOMET 4201 + wax (FL-4205)

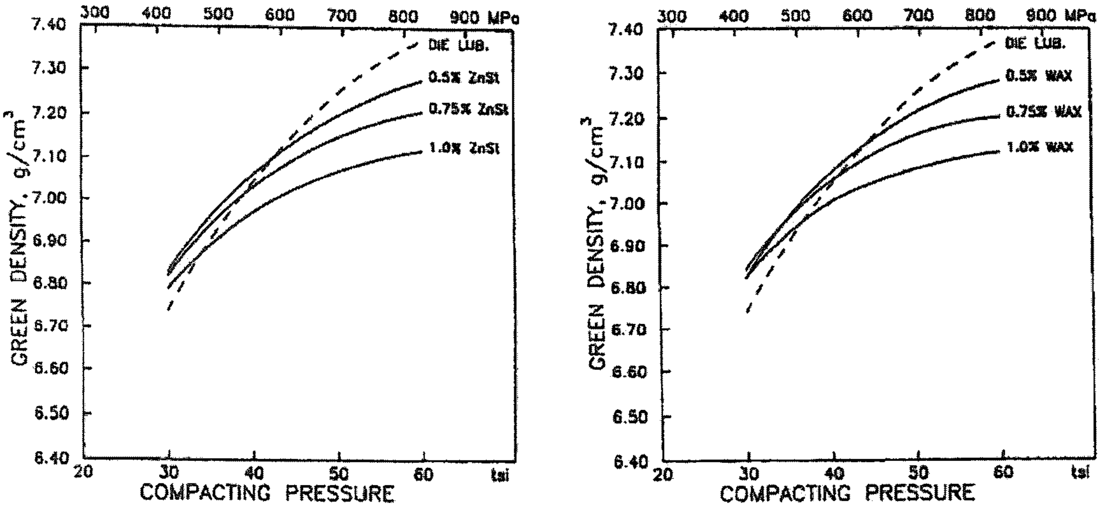


c) ATOMET 4601 + ZnSt (FL-4605)



d) ATOMET 4601 + wax (FL-4605)

Figure 2: Compressibility of ATOMET Low Alloy Steel Powders.



a) ATOMET 1001 + ZnSt (F-0005)   b) ATOMET 1001 + wax (F-0005)

Figure 3: Compressibility of ATOMET 1001.

Effect of Alloying Elements

The effect of alloying elements on compacting behaviour of low alloy steel powders can be derived by comparing compressibility data of these grades with those of ATOMET 1001. The compressibility curves of ATOMET 1001, 4201 and 4601 added with 0.5% C and 0.5% ZnSt are shown in Figure 4. This graph indicates that as the level of added alloying elements increases, the achievable density at a given compacting pressure decreases. However, the compressibility difference between the straight steel powder, ATOMET 1001, and low alloy powders, either ATOMET 4201 and 4601, decreases as the compacting pressure increases, as seen in Figure 5.

The slight decrease of compressibility shown in Figure 5 is likely related to solid solution hardening caused by the alloying of nickel and molybdenum. Indeed, it is well known that the introduction of solute atoms into solid solution in the iron atom lattice invariably produces an alloy which is stronger than the pure metal. However, the solid-solution strengthening effect is largely dependent upon the mode of introduction of the solute atoms into the iron. In substitutional solid solutions, the solvent and solute atoms are roughly of the same atomic radius and the solute atoms occupy lattice points in the crystal structure of the solvent. This is the case for Mn, Ni and Mo atoms dissolved in the iron lattice structure. In interstitial solutions, the solute atoms are much smaller than the solvent atoms and occupy interstitial positions in the solvent lattice. Interstitial elements, such as carbon, cause much larger solid solution hardening of the iron matrix than substitutional elements. Figure 6, derived from reference 4, illustrates the relative effect of different elements on hardness of iron.

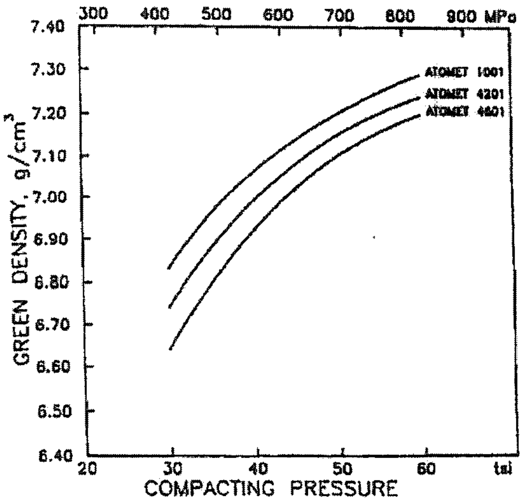


Figure 4: Compressibility of ATOMET Steel Powder Grades. (Mix composition: Steel Powder + 0.5% graphite + 0.5% zinc stearate).

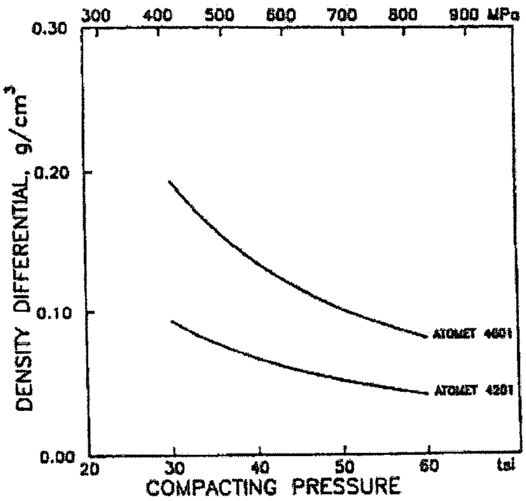


Figure 5: Differences in Green Density of Compacts Made of Low Alloy Powders Versus ATOMET 1001 Steel Powder. (Mix composition: Steel powder + 0.5% graphite + 0.5% zinc stearate).

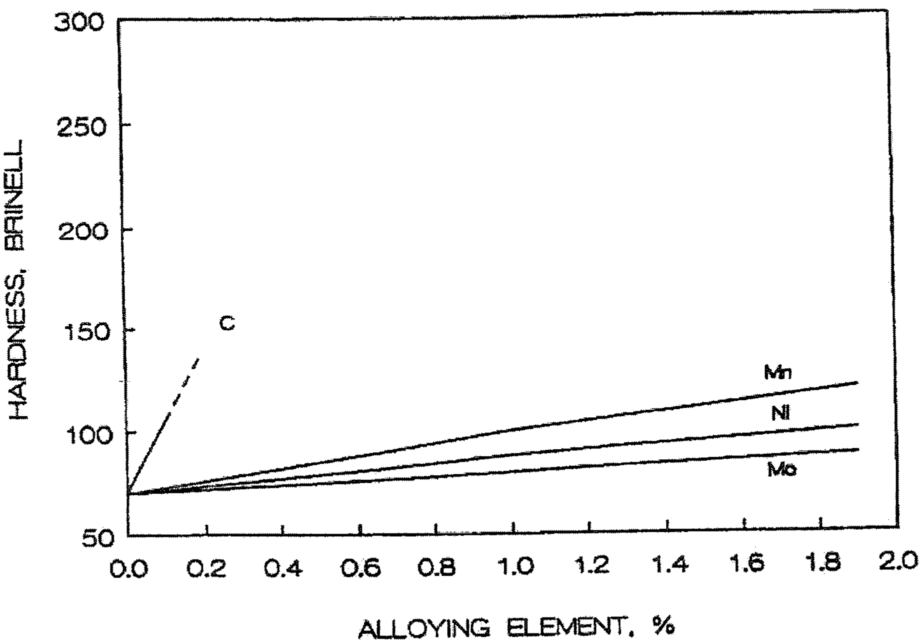


Figure 6: Effect of Alloying Elements on Hardness of Iron.

These metallurgical aspects were taken into consideration during the development of low alloy ATOMET powders, and the manufacturing process was designed to minimize the content of interstitial elements, namely carbon, in the final products. Since substitutional elements have much smaller hardening effect on iron, it was possible to retain most of the super-compressibility characteristics of ATOMET 1001 in the prealloyed powders in spite of the addition of up to 2.5% of metallic alloying elements.

Effect of Lubricant

Results of compressibility tests comparing wax to zinc stearate as lubricants for ATOMET 4201 based powder mixes are shown in Figure 7. These curves show that both lubricants have a similar impact on densification, the wax allowing slightly higher density to be achieved. Although not really significant at low compacting pressures, the selection of lubricant may have a sizeable impact on required compaction pressures when parts containing as much as 1% lubricant are pressed to densities above 7.0 g/cm^3.

More significant than the nature of the lubricant is the quantity of lubricant added to the powder mix. Indeed, it is clearly seen from the compressibility curves of Figure 2 that the amount of lubricant significantly affects the density that can be achieved during compaction. The nature and amplitude of this effect are however strongly dependent upon the compacting pressure.

At low compacting pressures, the addition of lubricant, either wax or zinc stearate, improves the densification of all powder mixes, as seen by comparing die lubrication with other curves of Figure 2. Varying the lubricant addition from 0.5% up to 1.0% has little effect on the density of parts pressed at 30 tsi.

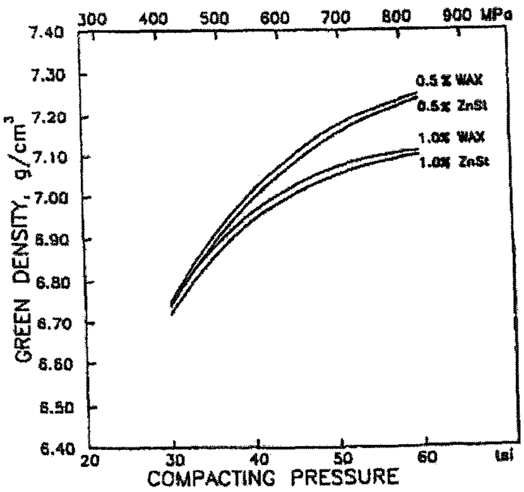


Figure 7: Effect of Nature of Lubricant on Compressibility of ATOMET 4201 Low Alloy Powder.

As the compacting pressure increases, green densities become more and more dependent upon the level of added lubricant. In all cases, the die lubrication curve crosses the curves of powder blends containing lubricant. At high compacting pressure, the lower the addition of lubricant, the higher the achieved density.

It is believed that at low compacting pressure, the presence of lubricant intimately mixed with the steel powder particles favors the initial rearrangement and interlocking of particles, thus resulting in higher densities than die lubrication. However, as the parts become more and more densified under the effect of increasing compacting pressure, the lubricant begins to occupy all the available pore space and becomes a limiting factor.

Indeed, because of its much lower specific gravity than steel, the lubricant occupies a much larger volume, for a given weight percentage. As density increases, the reduction of available pore space eventually counteracts the beneficial lubrication effect, limits the density gain and flattens the compressibility curve.

The percentages of theoretical density achieved during compaction of different steel powder grades containing various amounts of lubricant are given in Table 2. For these calculations, the theoretical density was defined as 100% dense part containing iron, graphite and zinc stearate with respective specific gravities of 7.86, 2.2 and 1.1 g/cm^3.

It is seen from the data of Table 2 that, for a given powder grade pressed at any given compacting pressure, the percentage of theoretical density increases with the level of lubricant addition. At low compacting pressures, such as 30 tsi, a zinc stearate addition of 1% increases the percent of theoretical density achieved by 6-7%. This well corresponds to the percentage of volume occupied by the lubricant.

However, when the compacting pressure is increased above 40 tsi, the density of the iron skeleton is further increased and not enough pore space is left in the compact to receive the added lubricant. In spite of a further increase in percent theoretical density, the actual density is decreased, as seen for parts pressed at 60 tsi in Figure 2. The level of lubricant addition should thus be adjusted to optimize the achieved density together with the required compacting pressure.

It is also worth noting in Table 2 the similarities in the compacting behavior of the three powder grades; pressed densities higher than 90% of theoritical density are readily achieved for all grades, thus confirming the highly compressible nature of the new ATOMET 4201 and 4601 low alloy powders.

TABLE 2

Percentage of Theoretical Density Achieved During Compaction of Steel Powders Mixed with 0.5% Graphite and Various Levels of Zinc Stearate

Powder Grade	ZnSt Addition, %	Compacting Pressure, tsi 30	40	50	60
ATOMET 1001	0.0	86.9	90.7	93.4	95.0
	0.5	90.1	93.7	95.6	96.7
	0.75	91.9	94.7	96.3	97.1
	1.0	93.1	96.1	97.7	98.5
ATOMET 4201	0.0	85.2	89.2	92.1	94.2
	0.5	89.5	92.8	94.9	96.1
	0.75	90.8	94.0	95.8	96.7
	1.0	91.8	94.8	96.4	97.0
ATOMET 4601	0.0	83.6	88.3	91.2	93.6
	0.5	88.2	91.9	94.3	95.6
	0.75	89.6	93.1	95.1	96.2
	1.0	90.8	94.0	95.8	96.9

CONCLUSIONS

1. The ability to manufacture low alloy steel powders exhibiting high compressibility characteristics has been demonstrated.

2. Although prealloying with nickel and molybdenum causes solid solution hardening of iron, the detrimental effect on compressiblity is relatively small because of the substitutional nature of such solid solutions.

3. The effect of alloying elements on compressibility of low alloy powder is more important at low compacting pressures. As the compacting pressure increases, the relative impact on compressibility decreases.

4. The addition of up to 1% lubricant, such as wax or zinc stearate, improves densification at compacting pressures lower than 40 tsi. However, as compacting pressure are increased above 40 tsi, the lubricant levels must be correspondingly reduced to permit optimization of density and compacting pressure.

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