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Lubrication Potential of Magnesium Stearate Studied on Instrumented Rotary Tablet Press

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ABSTRACT

The aim of this study was to investigate the lubrication potential of 2 grades of magnesium stearate (MS) blended with a mix of dicalcium phosphate dihydrate and microcrystalline cellulose. Force-displacement, force-time, and ejection profiles were generated using an instrumented rotary tablet press, and the effect of MS mixing time (10, 20, and 30 minutes) and tableting speed (10.7, 13.8, and 17.5 rpm) was investigated. The packing index (PI), frictional index (FI), and packing energy (PE) derived from the force-displacement profiles showed that MS sample I performed better than sample II. At higher lubricant mixing times, the values of PI were observed to increase, and values of FI and PE were observed to decrease for both MS samples. Lower values of area under the curve (AUC) calculated from force-time compression profiles also showed sample I to be superior to sample II in lubrication potential. For both the samples, the values of AUC were observed to decrease with higher lubricant mixing times. Tapping volumetry that simulates the initial particle rearrangement gave values of parameter a and C_{max} that were higher for sample I than sample II and also increased with lubricant mixing time. The superior lubrication potential of sample I was also established by the lower values of peak ejection force encountered in the ejection profile. Lower ejection forces were also found to result from higher tableting speeds and longer lubricant mixing times. The difference in lubrication efficacy of the 2 samples could be attributed to differences in their solid-state properties, such as particle size, specific surface area, and d-spacing.

KEYWORDS: Magnesium stearate, lubrication efficiency, force-displacement profile, force-time profile, particle rearrangement, ejection profile.

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INTRODUCTION

Tablet dosage forms have been the first choice in the development of new drug entities and account for some 70% to 80% of all pharmaceutical preparations.[1,2] As with other classes of pharmaceutical excipients, lubricating agents aid in the manufacture of tablets and ensure that the finished products are of appropriate quality. Lubricants with low shear strength but cohesive tendencies perpendicular to shear plane serve this purpose optimally.[3] Magnesium stearate (MS), with its low friction coefficient and large "covering potential," is an ideal lubricant widely used in tablet manufacturing.[4] The increased use of high-speed tableting and capsule machines has placed greater demands on lubricants, which are expected to help speed up the manufacturing process. This often requires the use of higher concentrations of MS, but because of MS's hydrophobic nature, increasing the concentration can adversely affect the tensile strength, flow properties, and dissolution rate.[5,6] Hence, there exists a need to control and optimize the level of MS in formulations to balance the lubrication potential against the effect on content uniformity, tablet hardness, compaction, and dissolution.

In a previous study, the lubrication efficacy of 6 samples of MS was investigated using a texture analyzer, and the results were correlated to the solid-state properties of MS samples.[7] The "net work done" method using a texture analyzer (with a load cell of 50 kg, equivalent of 500 N) was employed to simulate the lubrication efficacy of MS for use in a tamping capsule-filling machine, where forces in the range of 100 to 200 N are involved.[8] The study had identified the best and the worst performers and related their performance to solid-state properties. Tableting, which requires application of much higher forces (in the range of 5-15 kN), can be divided into 2 distinct stages: initial compression (reduction in bulk volume because of displacement of gaseous phase) and consolidation (increase in mechanical strength because of cold welding and fusion bonding between the particles).[9] An ideal lubricant needs to perform during both the stages. A texture analyzer–based method can only mimic slug formation in dosators and tamping capsule-filling machines. From a tableting point of view, the texture analyzer–based method only measures the particle rearrangement and slippage and is of limited value because it cannot simulate the higher

forces used in tablet compression. In a real tableting condition on a rotary tablet machine, a lubricant not only plays a role during particle rearrangement but, more critically, minimizes stress during ejection. An instrumented rotary tableting machine provides an attractive alternative for the study of basic compaction phenomena and gives a parametric view with respect to the actual tableting condition.[10]

The present study attempted to evaluate the lubrication potential of 2 MS samples (the best and worst performers as identified in the previous study) on an instrumented rotary tablet press using force-displacement and force-time compression profiles to quantify the packing and frictional behavior during initial particle rearrangement, and the ejection profile as a measure of tablet ejection. In addition, the effect of MS mixing time and tableting speed on the lubrication efficacy of MS was studied for both samples.

Materials and Methods

Materials

Two samples of MS from different manufacturers, designated as sample I (Lot no RMK01248, Famy Care, Mumbai, India; British Pharmacopoeia grade) and sample II (Lot no BR41, Global Medicine, India; Indian Pharmacopoeia grade), were procured. Dicalcium phosphate dihydrate (DCP) of granular grade (Engranule, Enar Chemie Private Limited, Gujarat, India) and microcrystalline cellulose (MCC) (Avicel PH102, FMC Biopolymer, Philadelphia, PA) were used as excipients.

Methods

Characterization of Excipients

The moisture content of the excipients was determined by Karl Fisher titration (Metrohm 794 Basic Titrino, Herisau, Switzerland). The instrument was calibrated with disodium tartrate dihydrate for the accuracy of moisture determination. A sample size of 100 to 120 mg was used for the determination of moisture content. The particle size of excipients was determined by optical microscopy by measuring the diameter along the longest axis for at least 300 particles (DMLP microscope, Leica Microsystems, Wetzlar, Germany). The melting point of MS samples was determined by a differential scanning calorimeter (821^e Mettler Toledo, Greifensee, Switzerland, operating with STAR system, version 5.1) with a temperature range of –10°C to 210°C at a heating rate of 5°C/min and nitrogen purge of 100 mL/min.

Preparation of the Excipient Blend

The selection of excipients for lubricant performance evaluation was based on the consolidation behavior of the excipients. A blend containing 92% DCP (brittle material) and 8% MCC (plastic material) was selected. The required amounts of DCP and MCC were weighed and mixed, and then MS was sieved through British Standard Sieve #60 and added in a geometric progression. The total blend was mixed in a Kalweka blender (VDM 4SP, Kalweka, Ahmedabad, India) at 20 rpm for 10 minutes. To differentiate the lubrication potential of the MS samples, blends were mixed for 10, 20, and 30 minutes at 20 rpm. Except otherwise indicated, a concentration of 0.2% wt/wt of MS was used throughout this study.

Tableting and Data Acquisition

The rotary tablet press (Mini II, Rimek, Ahmedabad) was equipped at 1 of the 8 stations with an 8-mm D-tooling with a flat punch tip. A feed frame was used for uniform die filling, and blind dies were used at all other positions. Precompression rollers were set out of function. The tablet weight was kept constant at 300 ± 4 mg, and the applied force was leveled by moving the pressure roller with a hand wheel. Humidity (40 ± 5% relative humidity) and temperature (25°C ± 5°C) conditions were controlled throughout the study. All blends were subjected to a constant main compression force (13.8 ± 0.2 kN) to minimize the effect of other experimental variables. Routine experiments were performed at 13.8 rpm (round time of 4358 msec). However, for the study of tableting speed, an additional 2 speeds of 10.7 and 17.5 rpm were selected (round time of 5604 and 3419 msec, respectively).

Data was acquired by Portable Press Analyzer (PPA) version 1.2, revision D (Data Acquisition and Analyzing System, PuuMan Oy, Kuopio, Finland), through an infrared (IR) telemetric device with 16-bit analog-to-digital converter (6 kHz). Force was measured by strain gauges at upper and lower punches (350 Ω, full Wheatstone bridge; I. Holland Tableting Science, Nottingham, UK), which were coupled with displacement transducers (linear potentiometer, 1000 Ω). Upper and lower punch data were recorded and transmitted on separate channels by individual amplifiers ("Boomerangs"). The amplifiers truncated the raw data from 16 bit to 12 bit after measuring to check IR transmission (data transmission rate: 50 kbaud; internal data buffer: 1024 measurement points). Analysis of compaction data was performed by the PPA software. The accuracy of force and displacement transducers was 1% and 0.02%, respectively. The suitability of the data acquisition system has previously been reported.[10]

Tapping Volumetry

Tapping experiments were performed in triplicate on a tap density apparatus (ETD-1020, Electrolab, Mumbai, India) equipped with a 10-mL graduated glass cylinder. Blends

containing MS were gently poured through a funnel into a graduated cylinder, and the tapped volume was read to the nearest millimeter at 0, 50, 100, 200, 300, 500, 700, 1000, 1300, 1700, and 2000 tap numbers.

Statistical Analysis

SigmaStat version 2.03 (Systat Software Inc, SPSS Ltd, San Rafael, CA) was employed for all regression and statistical analysis. Data are expressed as mean ± SEM. To check whether there was any significant difference in the mean of the treated groups, and hence the lubrication efficacy of different blends, comparison of the mean values of various groups was performed by 1-way analysis of variance followed by multiple comparisons using the Tukey test. The data was analyzed and it showed a normal distribution at 99% confidence limits. Differences between groups were considered significant when $P < .01$.

Results and Discussion

Characterization of Excipients

The moisture content of DCP and MCC was found to be 0.32% and 4%, respectively. The median particle size for DCP and MCC was found to be 110 to 140 μm and 80 to 100 μm, respectively. The moisture content and the particle size distribution of both the samples have been reported previously.[7] The values of the stoichiometric ratio of water molecules per molecule of magnesium stearate present in the crystal structure for sample I and sample II were found to be ~1.8 and 1.86, respectively. The results indicated that both the samples were dihydrate. The percentage distribution of particle size ($d_{\%}$) was calculated for both the samples of MS. The $d_{1\%}$, $d_{50\%}$, and $d_{95\%}$ for sample I were >24.12 μm, >6.12 μm, and >1.12 μm, respectively; and for sample II were >84.63 μm, >24.42 μm, and >1.38 μm, respectively.[7] The melting point of samples I and II was found to be 108°C to 120°C and 112°C to 125°C, respectively.

Selection of Excipients and MS Concentration

DCP is a brittle material. The fragmentation under confined loading generates new surfaces, which increases the surface area of the particles over which the lubricant particles can distribute. DCP's brittle nature and high propensity toward fragmentation make it lubricant-insensitive. On the contrary, MCC, which consolidates by plastic deformation, remains lubricant-sensitive. Therefore, the blend containing a higher proportion of DCP was used in the study. The lead was also indicated in a previous study on the lubrication potential of MS.[7] The use of MS at 1% and 2% wt/wt in the selected excipient blend gave a very low ejection force that was not quantifiable. The aim of the investigation was to differentiate the lubrication potential of MS using different compaction profiles generated during tableting of the blend and to identify the relationship between lubrication potential and the solid-state properties of MS during a real tableting condition. Hence, lower concentrations were screened and a concentration of 0.2% wt/wt was selected for further experimentation.

Force-Displacement Compression Profile

The tendency of a material to undergo rearrangement, fragmentation, plastic deformation, and/or elastic recovery can be expressed and quantified as numerical values from a force-displacement curve.[11-13] Figure 1 illustrates the different energies involved during the complete compression cycle and the stage-specific energy allocations of different stages from the force-displacement compression profile. Triangle ACD describes the mechanical energy (energy of compaction); triangle BCD is the theoretical energy (energy of compaction, excluding initial packing phase, AB); curve BCD is the total energy (energy involved during compaction, excluding initial packing and interparticulate friction); curve BCB is the frictional energy (friction arising due to particle-particle and particle-die wall friction, ie, difference between theoretical energy and total energy); curve CDE is the elastic energy (energy released as a result of elastic deformation during compression unloading); and curve BCE is the net energy (energy required to yield a particle under force).

Under a low applied force (at the start of the compression cycle), the initial portion of the force-displacement profile gives information about particle rearrangement. The particle sliding and rearrangement in this phase does not contribute

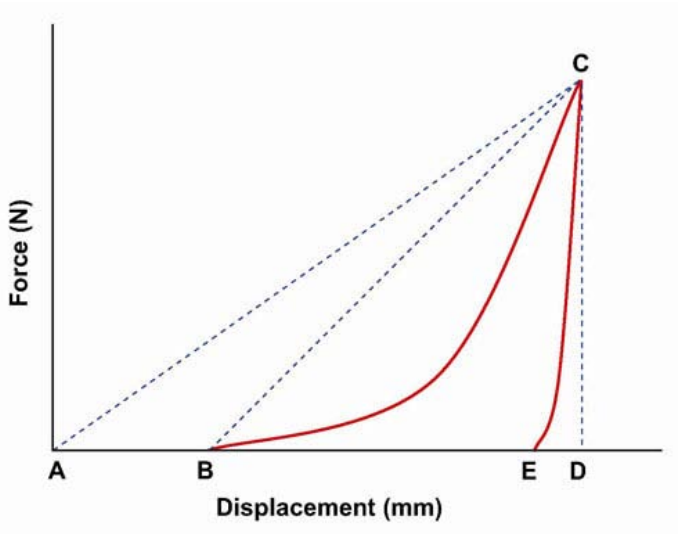

Figure 1. A theoretical force-displacement compression profile showing the different areas of the compression event.

Table 1. PI, FI, PE, and AUC for Blends Mixed for Varying Time Periods (n = 6)*

Mixing Time	10 Minutes				20 Minutes				30 Minutes			
Sample	PI	FI	PE (J)	AUC (Nsec)	PI	FI	PE (J)	AUC (Nsec)	PI	FI	PE (J)	AUC (Nsec)
I	0.4485 (0.006) †abc	0.6157 (0.006) †abc	8.73 (0.08) †abc	53.58 (0.97) †abc	0.4634 (0.003) †a, ‡c	0.6006 (0.002) †a, ‡c	7.99 (0.13) †ac	49.39 (0.08) †a, ‡c	0.4989 (0.005) †a	0.5749 (0.003) †a	7.33 (0.11)†a	47.17 (0.15)†a
II	0.4409 (0.003) †abc	0.6206 (0.005) †a, ‡bc	9.10 (0.17) †abc	54.97 (0.75) †a, ‡bc	0.4491 (0.003) †a, ‡z	0.6118 (0.003) †a, ‡cz	8.68 (0.03) †acz	53.51 (0.34) †az, ‡c	0.4528 (0.005) †az	0.6014 (0.002) †az	8.18 (0.09)†az	50.49 (0.97)†az
0% MS (control)	0.3195 (0.016)	0.6563 (0.009)	10.78 (0.39)	58.66 (1.14)	—	—	—	—	—	—	—	—

*PI indicates packing index; FI, frictional index; PE, packing energy; AUC, area under the force-time curve; MS, magnesium stearate.
†$P < .001$.
‡$P < .01$.
[a]vs control.
[b]vs 20 minutes.
[c]vs 30 minutes.
[z]vs sample I.

significantly to the densification.[14,15] The phenomenon of initial particle rearrangement can be expressed as packing index (PI) and frictional index (FI), each of which involves 2 different energies that are related by linear law over the entire force profile. PI relates the transformation of mechanical energy (ME) into theoretical energy (ThE), while FI characterizes the transformation of theoretical energy into total energy (TE). They can be presented as follows:

$$PI = 1 - (ThE/ME) \quad (1)$$

$$FI = 1 - (TE/ThE) \quad (2)$$

Lubricants play a significant role in facilitating the packing of particles,[16] which is reflected as a change in the value of PI, FI, and packing energy (PE). Table 1 shows the values of PI, FI, and PE obtained from the force-displacement compression profile for blends prepared using samples I and II, each mixed at 3 different mixing times (10, 20, and 30 minutes), along with the control (no MS added). Values of PI increased with an increase in mixing time for both sample I and sample II, and values for sample I were greater than those for sample II for any given mixing time. PI is a measure of a material's ability to pack under the influence of interparticulate and die-wall frictions at a very low applied force. The mixing time of MS significantly altered the PI parameter for sample I ($P < .01$) but not for sample II. When samples I and II were compared, a significant difference in the value of PI was apparent at a mixing time of 20 and 30 minutes, although the difference was not significant at 10 minutes.

FI represents the sum total of interparticulate and die-wall frictions encountered during this phase. The energy required for initial packing under particle rearrangement was also calculated by considering the area corresponding to PE (triangular area ABC, Figure 1) from the force-displacement compression profile. Values of FI and PE were observed to decrease with higher mixing time of MS and were lower for sample I than for sample II at any mixing time. The mixing time of MS significantly altered the FI and PE parameters for both sample I and sample II ($P < .01$). A significant difference in the value of FI and PE was apparent when samples I and II were compared at a mixing time of 20 and 30 minutes but not at 10 minutes (Table 1). These results indicate that mixing time has an influence on the surface distribution of MS particles and a longer mixing time imparts greater surface distribution, which affects the frictional forces arising from the interparticulate and die-wall frictions.

Force-Time Compression Profile

A force-time compression profile (Figure 2) can also be used to distinguish the various stages of compression.[17] The area under the curve (AUC) of the initial phase of the force-time compression profile (area a, below 2.8 kN, Figure 2) was used as a quantitative measure of the material's ability to rearrange under the influence of frictional forces resulting from the sliding of the particle planes with respect to each other and the die-wall frictional forces.[18,19]

Table 1 lists the values of AUC calculated from the initial region of the force-time compression profile. Sample I yielded a lower value of AUC than did sample II, which was

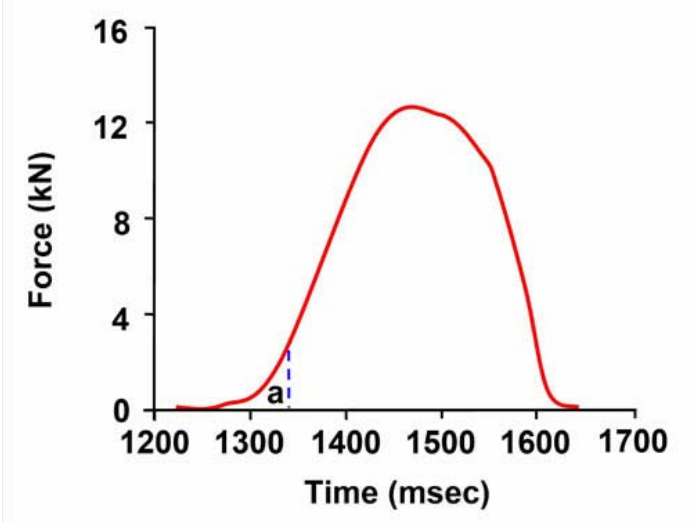

Figure 2. A representative force-time compression profile obtained from powder bed compression.

attributed to the lower force required to rearrange particles in sample I. As the mixing time was increased, the force required to rearrange particles up to a certain densification was reduced. This observation also confirmed the effect of lubricant distribution on the performance. Values of AUC were significantly affected by the mixing time of MS for both sample I and sample II ($P < .01$). A significant difference in the value of AUC was noticeable when samples I and II were compared at a mixing time of 20 and 30 minutes but not at 10 minutes. The results from the force-time profile were parallel to those obtained from the force-displacement profile. This confirmed the ability of parameters obtained from force-displacement and force-time profiles to represent the phenomenon of initial particle rearrangement under the influence of MS.

Tapping Volumetry

Tapping volumetry gives an approximation of volume reduction under the influence of lubricant and can be modeled using the Kawakita equation, which relates the state of volume reduction as a function of applied stress.[20] It is generally accepted that the Kawakita equation is best used for low pressures and high porosities and can be applied to data obtained from tapping volumetry.[21] For tapping experiments, the Kawakita equation can be expressed as follows:

$$n/C = [n/a + 1/ab] \tag{3}$$

$$C = \frac{[V_O - V_n]}{V_O} \tag{4}$$

where n is the tap number and a is the value of initial porosity that corresponds to the total portion of reducible volume. V_n and V_0 are the powder volume at the initial and nth tapped state, respectively. C describes the relative volume reduction, and b is a constant.

Results of tapping volumetry describing the Kawakita parameter (a) and maximum reducible volume (C_{max}) for blends containing 0.2% wt/wt of MS samples I and II, each mixed for 10, 20, and 30 minutes, and the values for control are presented in Table 2. The values of both a and C_{max}

Table 2. Kawakita Parameter (a) and Maximum Reducible Volume (C_{max}) for Blends Mixed for Varying Time Periods Along With the Values of Control Sample (n = 3)*

Mixing Time	10 Minutes		20 Minutes		30 Minutes	
Sample	a	C_{max}	a	C_{max}	a	C_{max}
I	0.2374 (0.0002)$^{\dagger abc}$	0.2317 (0.0017)$^{\dagger a,\ \ddagger bc}$	0.2494 (0.0003)$^{\dagger ac}$	0.2433 (0.0017)$^{\dagger a,\ \ddagger c}$	0.2665 (0.0018)$^{\dagger a}$	0.2567 (0.0017)$^{\dagger a}$
II	0.2249 (0.0004)$^{\dagger abz}$	0.2183 (0.0017)$^{\dagger az,\ \ddagger b}$	0.2409 (0.0007)$^{\dagger a,\ \ddagger z}$	0.2317 (0.0017)$^{\dagger a,\ \ddagger z}$	0.2476 (0.001)$^{\dagger a,\ \ddagger z}$	0.2367 (0.0017)$^{\dagger a,\ \ddagger z}$
0% MS (control)	0.2026 (0.005)	0.1950 (0.0029)	—	—	—	—

*MS indicates magnesium stearate.
†$P < .001$.
‡$P < .01$.
[a]vs control.
[b]vs 20 minutes.
[c]vs 30 minutes.
[z]vs sample I.

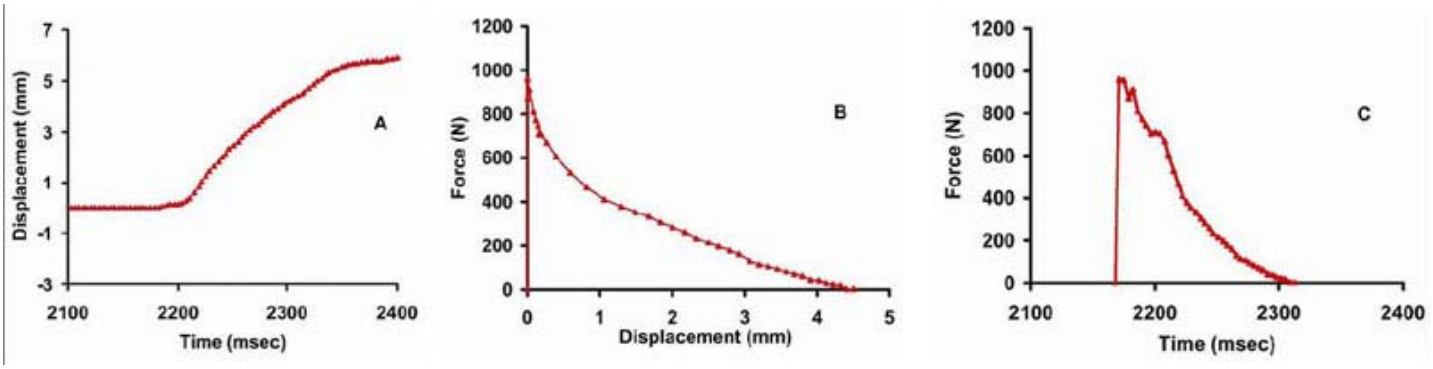

Figure 3. Ejection profiles: (A) displacement-time, (B) force-displacement, and (C) force-time; profiles obtained at 13.8 rpm.

(maximum relative volume reduction) obtained from Kawakita analysis increased with higher mixing times for sample I and sample II. However, greater volume reduction was observed for sample I than for sample II. Lubricant mixing time influenced the total volume reduction because the lubricant distribution at the particle level assists the particle rearrangement under tapping by reducing the interparticulate friction. From a mathematical point of view, the *a* term describes the total amount of reducible volume while considering the packing efficiency of the powder under applied stress. The mixing time of MS significantly altered the volume reduction parameters *a* and C_{max} for samples I and II ($P < .01$). A significant difference in the values of *a* and C_{max} was evident at all mixing times when samples I and II were compared.

Ejection Profile

The force necessary to eject a tablet involves the distinctive peak force required to initiate ejection by breaking the die-wall tablet adhesion.[22] The second stage involves the force required to push the tablet up the die wall, and the last force is required for ejection of a tablet from the die.[23] The distance traveled by the lower punch to push the tablet up to die level is the ejection displacement (Figure 3a). The integration of the areas under the force and displacement is the ejection work—that is, energy utilization during ejection (Figure 3b). Ejection displacement and ejection work at each lubricant mixing time are reported in Table 3. The peak ejection force (Figure 3c) recorded during tableting was used as a measure of the ejection. Each compression was performed under a similar main compression force so the possibility of a change in the ejection force being caused by a change in the main compression force could be ruled out.

The ejection force results obtained for sample I and sample II, each at 10, 20, and 30 minutes of mixing, are presented in Figure 4a. The observed corresponding value of the ejection force for the control blend (no MS added) was 1736 ± 12.1 kN. A significant difference in ejection force was evident at all mixing times when samples I and II were compared. The ejection force values were significantly different at all mixing times for sample I ($P < .01$). However, for sample II, the difference was significant between the blends prepared at mixing times of 10 and 20 minutes, but not significant between the blends prepared at mixing times of 20 and 30 minutes. This indicated optimal distribution of MS over particles of DCP and MCC, occurring in 20 minutes, with no further improvement thereafter. The latter is reflected as no futher reduction in ejection force. The values of ejection displacement and work (Table 3) calculated for the above experimental sets supplement the data obtained for ejection force.

To investigate the effect of tableting speed on the lubrication performance of MS samples, tableting was done at 3 speeds: 10.7, 13.8, and 17.5 rpm. Results showed that as the

Table 3. Values of Ejection Displacement and Ejection Work Obtained for Blends Mixed for Varying Time Periods and Compressed at Different Tableting Speeds (n = 3)*

		Mixing Time (min)			Tableting Speed (rpm)		
Sample	Ejection Parameter	10	20	30	10.7	13.8	17.5
I	Displacement (mm)	4.69 (0.02)	4.80 (0.03)	4.71 (0.01)	4.60 (0.04)	4.85 (0.06)	4.76 (0.04)
	Work (J)	1.17 (0.08)	0.92 (0.05)	0.79 (0.03)	1.60 (0.08)	1.01 (0.06)	0.94 (0.05)
II	Displacement (mm)	4.81 (0.08)	4.78 (0.01)	4.64 (0.07)	4.70 (0.03)	4.77 (0.02)	4.83 (0.03)
	Work (J)	1.50 (0.10)	1.14 (0.07)	1.02 (0.04)	1.91 (0.3)	1.18 (0.02)	1.09 (0.04)

*Values of control blend (no magnesium stearate added) for ejection work and ejection displacement were 2.92 (0.1) kN and 4.95 (0.06) mm, respectively.

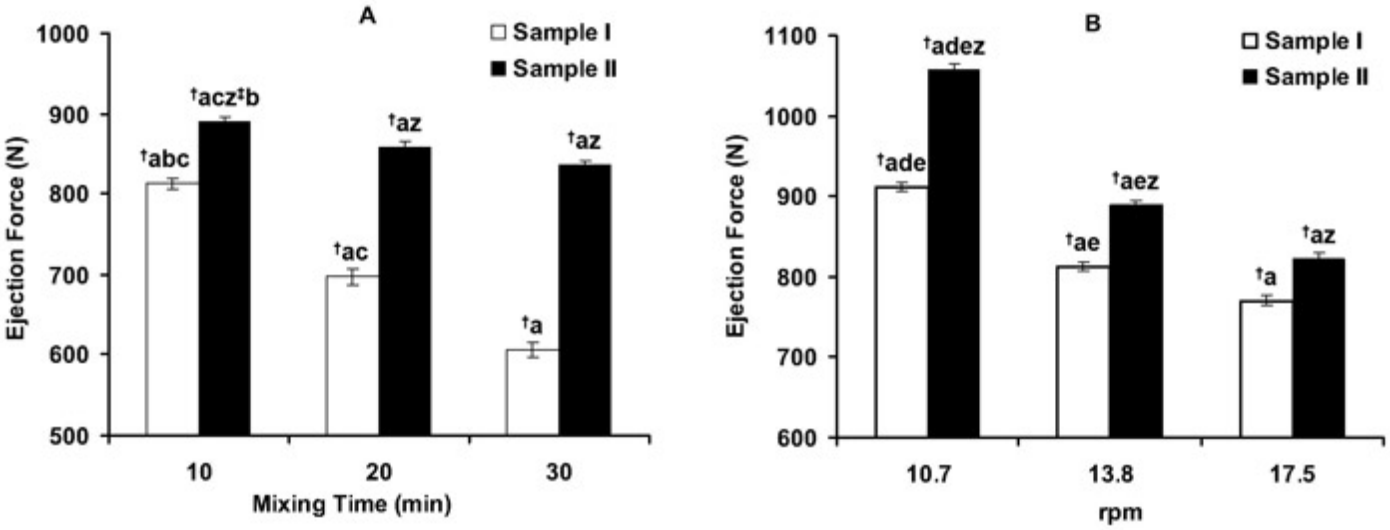

Figure 4. Average ejection force values for 24 tablets for blends (A) mixed for varying time periods, and (B) compressed at different tableting speeds. †$P < .001$; ‡$P < .01$; [a]vs control; [b]vs 20 minutes; [c]vs 30 minutes; [d]vs 13.8 rpm; [e]vs 17.5 rpm; [z]vs sample I.

tableting speed was increased, the values of the ejection force for both the MS samples decreased (Figure 4b). The tableting speed significantly altered the ejection force for both sample I and sample II ($P < .01$). A significant difference in the ejection force was also observed at all 3 tableting speeds when samples I and II were compared. The plastic deformation and fragmentation tendency of materials are time-dependent and occur at different rates during the compaction sequence, so the tablet mass is never in a state/strain equilibrium during the actual tableting event.[24] This means that the rate at which load is applied and removed may be a critical factor in elastic recovery and radial transmission force. The ejection force depends on the main compression force; hence, while the effect of dwell time was studied, the main compression force was kept constant. An increase in dwell time resulted in an increase in the main compression contact time of the upper and lower punch with the compact, which resulted in an increase in the radial force transmission to the die wall and a greater fragmentation propensity of brittle materials. The radial force acts as an indicator of friction forces between the compact and the die wall. Hence, increasing the dwell time is expected to increase the ejection force.[25] The extent of fragmentation of DCP (a major component in the blend) is also affected by the dwell time of the material, since at a higher dwell time, DCP particles undergo more fragmentation than they do at a lower dwell time. The lubricant surface distribution during the actual tableting event is affected by the extent of new surface created. Hence, higher tableting speed (reduced dwell time) reduces the chance for the formation of new surfaces. The reduction in ejection force at increased speed can therefore be attributed to the lower fragmentation propensity. The values of ejection force were also substantiated by the results of ejection work (Table 3).

Solid-State Properties and Lubrication Potential

The solid-state properties of MS samples and the lubrication potential using a texture analyzer were reported.[7] Molecular-level (d-spacing) and particle-level (habit, particle size, surface area) properties of the 2 MS samples used in this study are reproduced in Table 4. It can be seen that the 2 samples differ substantially in their crystal habit (plate vs irregular), particle size (1.12 μm vs 1.38 μm), specific surface area (6.63 m^2/g vs 1.66 m^2/g), and d-spacing (11.7 Å vs 9.9 Å). These differences may contribute critically to the lubrication potential of MS. Compared with sample II, sample I exhibited a smaller particle size and a higher surface area, which helped the MS particles to distribute themselves well on the excipient surface. Sample I had flat, platelike crystals, whereas agglomerates were present in sample II, which

Table 4. Molecular Level (d-Spacing) and Particle Level (Habit, Particle Size, Surface Area) Properties of Magnesium Stearate Samples[7*]

Solid-State Property	Sample I	Sample II
Particle size (μm)	$d_{1\%} > 24.12$	$d_{1\%} > 84.63$
	$d_{50\%} > 6.12$	$d_{50\%} > 24.42$
	$d_{95\%} > 1.12$	$d_{95\%} > 1.38$
BET specific surface area (m^2/g)	6.63	1.66
Monolayer volume,† V_m at STP (cc/g)	1.5224	0.3814
Crystal habit	Plate	Irregular
d-spacing (Å)	11.7	9.9

*BET indicates Brunauer-Emmett-Teller; STP, standard temperature and pressure. $d_{1\%}$, $d_{50\%}$, and $d_{95\%}$ represent the 1%, 50%, and 95% distribution of particle size (μm), respectively.
†The larger the surface area, the greater the volume of gas adsorbed.

again would affect the distribution over the particles. An increase in mixing time with MS led to increased surface distribution, which resulted in favorable particle rearrangement and a reduction in ejection force. Hence, the better performance of sample I can be attributed to its superior solid-state properties. A difference in the d-spacing values for samples I and II was also apparent from powder X-ray analysis. Shearability of a lubricant is a desired attribute and is related to elongation of lattice spaces of the crystal.[6] A crystal with a longer lattice space would be expected to be a better performer (here, sample I over sample II).

CONCLUSIONS

An instrumented rotary tablet press can be used to study the role of MS in initial particle rearrangement and ejection phases. PI, FI, PE, AUC of the force-time compression profile, and ejection force can be used to differentiate the lubrication potential of different MS samples as well as the effect of lubricant mixing time and tableting compression speed. Solid-state properties of the MS samples—crystal d-spacing, particle size, and specific surface area—have an influence on the lubrication performance.

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