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An application for zirconia as a pharmaceutical die set

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Abstract

The main objective of this study was to investigate the possible use of zirconia as a material for the manufacture of punches and dies for use in tableting machines and to study its effect on ejection of tablets made from different formulations. In order to achieve this objective, the compaction properties of three commercially available direct compression excipients were examined with the help of a compaction simulator, over a range of compaction pressures using steel and zirconia tooling. The data obtained for all materials indicated that, for a particular compression speed, the work required to eject the tablet from the die, i.e., the work needed to overcome die wall friction during ejection, was lower in zirconia tooling than steel tooling. Scanning electron microscopy (SEM) was employed to investigate the excipients powders and compact surfaces for contrasting particle morphology before and after compaction. Electron probe microanalysis (EPMA) was also carried out on the representative tablets compacted at high speed using zirconia tooling and no shedding of zirconia into the tablets was detected.

Keywords: Compaction; Die-wall friction; Excipients; Pharmaceutical dies; Steel; ZrO_2

1. Introduction

Tablets are the most common dosage form. Production should be as efficient and economical as possible. Pharmaceutical tablets comprise the active ingredient and an excipient. Generally speaking, an excipient accounts for most of the weight or volume of a tablet. An excipient can be described as any more or less inert substance added to a prescription in order to confer a suitable consistency or form to the drug, in other words; a vehicle.[1] Tablets are usually prepared by the instantaneous compression of a powder, between two punches in a die. The force for compression may be supplied by either the upper and lower punches or by either, but in neither case does all of the applied force go into compressing the powder. Although some of the force is lost in heat and sound energy a major proportion is absorbed in overcoming friction. Friction generated during tableting is a result of interparticle friction and the friction between the compressed particles in the powder bed and the die wall and the upper and lower punches. Friction can decrease the transmission of axial and radial force to the powder, resulting in non-homogenous distribution of porosity and density in the tablets. This in turn can cause a significant tablet-weight variation as well as chipping, capping and lamination of the tablets. Friction can also damage the machine and tablets during ejection. Moreover, high temperatures generated during compression can affect drug stability.[2]

In order to minimise these problems, it has been usual to incorporate a lubricant in small quantities in the powder or granules to be tabletted. An ideal lubricant should act by reducing shear strength at the interface between the tablet and the die wall, reducing the coefficient of friction and hence the frictional force at a given load. Reducing the coefficient of friction has a number of advantages such as reducing the work required to compact the powder and perhaps more importantly, reducing the work required to eject the tablet. Picking and sticking of material to tooling surfaces may in part be attributed to ineffective lubrication. An ideal lubricant should have no adverse effects on the formulation, be inert and cosmetically acceptable with respect to

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other ingredients. Furthermore, it should be unaffected by changes in process variables, consistent from batch to batch, readily available and cheap. A wide range of boundary lubricants are available for pharmaceutical applications. Among these, magnesium stearate is by far the most widely used, but the use of it as a lubricant has, however, given rise to a number of disadvantageous secondary effects on the performance of tablets. The most noticeable of these effects are that it is an extremely hydrophobic powder that can adversely affect the bioavailability of drugs by hindering dissolution and it 'softens' tablets leading to subsequent processing problems. It is also undesirable in soluble tablets where it produces a surface film or scum on the glass of water in which the tablet is dissolved. Moreover, the mixing time used to incorporate the magnesium stearate in the other ingredients of the tablet formulation is critical and can influence the physico-mechanical properties of the tablets produced. Other frustrating aspects in the use of magnesium stearate are the huge intersupplier and batch-to-batch variations in these properties, which cause manufacturing problems. As most magnesium stearate (and all of the grades that have good lubrication properties) is manufactured from animal sources it is also unsuitable for a wide range of applications. Alternative powdered lubricants are available including other stearate salts, close derivatives and other hydrophobic materials (e.g. hydrogenated vegetable oil), along with a number of more esoteric materials (e.g. sodium benzoate and sodium lauryl sulphate). These are generally not widely used but it is generally considered within the industry that they may slightly ameliorate the problems of lubrication but no means eliminate them.[3]

There are different ways to limit the deteriorating effect of magnesium stearate on tablet properties, without affecting the lubrication properties to a large extent. Undoubtedly, the best method is omitting a lubricant in a tablet formulation and applying alternative lubrication methods, mostly involving modifications to tablet machines. Researches have suggested that improvements in the condition of finished toolings can minimise friction during tableting.[3] The addition of exact amount of a suitable lubricant directly onto punch and die surfaces immediately after tablet ejection has also been reported.[4,5] Other techniques are pre-treatment of die walls by phosphation, using bonded PTFE tipped punches and die linings or dies made from steel with lubricant inclusions or cycling compressions of a carrier formulations first containing a lubricant, to create a lubricant film on the die wall, followed by compression of the unlubricated formulation. Such methods have been received with limited success or are expensive.[5–7]

The punches and the dies of the moulding devices used for the manufacture of tablets are typically formed of steel. Because of the repeated use of the punches within their associated die, to form the material into tablets, both the punches and the die are subjected to a high degree of wear. In commercial practice, hardened steel is presently used for the manufacture of the punches and dies. Even with such hardened steel materials, lubricated in the manner described above, the severe abrasion to which the parts are subjected results in wear, and may result in the shedding of small amounts of the metal into the substrate. The presence of that material in the resulting tablets, albeit being substantially non-toxic in the amounts obtained in normal practice, is undesirable.

Advanced ceramics such as zirconia (ZrO_2), alumina (Al_2O_3), silicon nitride (Si_3N_4), and silicon carbide (SiC) offer potential as alternative materials for wear resistant parts. Among these, transformation-toughened zirconia ceramics with their improved toughness and low friction coefficient appear to be ideal wear resistant materials in a variety of engineering applications. Zirconia has been found to have particularly suitable properties for use in those parts in tableting machines that will be in contact with the material to be compacted. It is a very hard material, and thus resistant to abrasion. The use of zirconia offers significant advantages in terms of wear resistance, and thus in terms of the length of the useful life of the parts. Zirconia is substantially non-toxic when ingested in small quantities so that, should any abraded material from the shaped part enter the tablet formulation, that will not detrimentally affect the acceptability of the tablets, whether for pharmaceutical or other use. Other properties of zirconia, which it is thought may contribute to its excellent performance in the manufacture of tablets, are its anti-static properties, non-magnetic nature, low thermal conductivity and good corrosion resistance. A consequence of the advantageous combination of such properties is that the amounts of material shed into the tablet formulation is likely to be considerably reduced as compared with the steel parts conventionally used, and may be substantially eliminated. It is also expected that the tablets manufactured using zirconia members may be of improved strength. As a matter of fact, zirconia has found several medical uses such as implant, femoral heads for hip replacement, etc.[8,9] A further advantage of zirconia is that, because of its relative hydrophilicity, it offers a low coefficient of friction in the context of moulding. It is thought that this unexpectedly low coefficient of friction is accounted for by the fact that the surface of the zirconia attracts a monolayer of water molecules, which acts as a lubricant during the manufacturing process.

The aim of this study was to examine the possible use of zirconia as a material for the manufacture of punches and dies for use in tableting machines and to study its effect on ejection of tablets made from different formulations.

2. Experimental

2.1. Test materials

Although the principles governing direct compression have been known many years, the technique has only recently become more established as a result of the introduction of excipients specifically designed for direct compression. These excipients are not only directly compressible themselves, but can also be mixed with a large proportion of drug susbtance with no significant deterioration in tablet quality. Successful compaction and tableting of pharmaceutical excipients requires an understanding of their fundamental properties. These properties include both physicochemical and mechanical properties and dictate how formulations will behave during tableting process. Detailed information can be found in the relevant literature.[10,11] The direct compressible excipients used to make the tablets in this study were selected to represent a variety of deformation characteristics (see Table 1). Namely, microcrystalline cellulose (Emcocel 90M, Mendell UK Ltd., UK) was chosen as representative of plastically deforming materials. Materials that exhibit at least some brittle fractures, in other words, fragmentation, were typified by dibasic calcium phosphate dehydrate (Emcompress, Mendell UK Ltd., UK) and sprayed dried lactose (Zeparox, Borculo Why Products Ltd., UK). These materials were employed as received from the suppliers. All powders were each lubricated with 0.5% w/w magnesium stearate (GPR grade, BDH, England) for 5 min in a Turbula mixer at slow speed. Before the addition, magnesium stearate was sieved down to a coarse sieve with a brush to break down the agglomerates. Mixing operations were performed in a 500-ml glass bottle. All powders were conditioned before use at least for one day in a desiccator at a relative humidity of 44% and at room temperature.

2.2. Electron microscopy

Scanning electron microscopy (SEM) was employed to qualitatively characterise both the morphology of the excipient powders and compact surfaces. The SEM used was a Jeol JSM-6310 analytical microscope. Prior to the investigation, the samples were coated with gold using a sputter coater (model: S150B, Edwards High Vacuum Ltd., England) in order to avoid the build-up of local electrical charges. In addition, Electron Probe Microanalysis (EPMA) work was performed on the representative tablets compacted using zirconia tooling in order to detect if there was any shedding of zirconia into them. The EPMA employed was a Jeol JXA-8600 superprobe electron probe microanalyser. It is equipped with four computer controlled WDS spectrometers, containing a range of crystals such that the whole spectrum can be covered. All the tablets were coated with carbon before the analyses to prevent charging of local areas of the surface and consequent distortion and deflection of the electron beam. The coating unit used for this purpose was model 12E6 (Edwards High Vacuum Ltd., England).

2.3. Compaction

The mixtures were compressed into tablets on a high speed compaction simulator (ESH Testing Ltd., UK) fitted with 10 mm diameter flat-faced round F-tooling, manufactured from steel and yttria stabilised zirconia (see Fig. 1). Zirconia punches and dies were originally manufactured whole using conventional technology by a commercial company (Dynamic Ceramic Ltd., UK). The drawings and specifications were provided by conventional tooling manufacturers (Manesty UK). The tolerances for air space (the fit between die and punch allows for air to be excluded during initial compaction

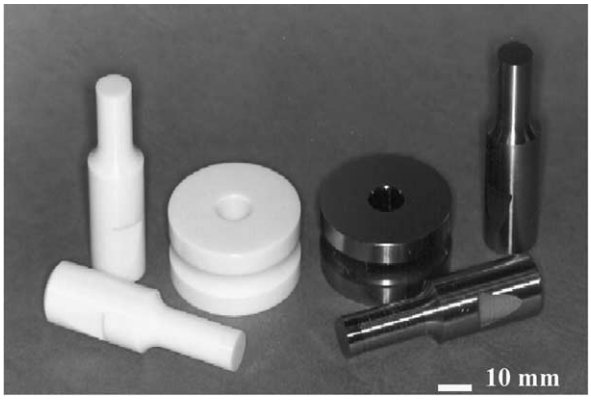

Fig. 1. 10 millimetre flat-faced F-tooling manufactured from zirconia and steel.

Table 1
List of the excipients, empirical formula, manufacturers, and lot numbers

Excipient	Empirical formula	Manufacturers	Batch number
Microcrystalline cellulose (Emcocel 90M)	$(C_6H_{10}O_5)_n$ where n≈220	Mendell UK Ltd., UK	9S5025
Spray dried lactose (Zeparox)	$C_{12}H_{22}O_{11}$	Borculo Whey Products UK Ltd., UK	733710
Dibasic calcium phosphate dihydrate (Emcompress)	$CaHPO_4.2H_2O$	Mendell UK Ltd., UK	R18E
Magnesium stearate	$C_{36}H_{70}MgO_4$	GPR grade, BDH, England	–

phases of tableting) met or exceeded the industry specifications. The compaction speed was set to 100 mm/s, corresponding to the main compaction time of approximately 0.345 s. A single saw-tooth control profile was chosen to provide the main compaction pressures. The die was filled manually, sufficient powder being used to produce a tablet thickness of about 2.5 mm at zero theoretical porosity. The machine was equipped with two linear variable displacement transducers (LVDT). The distortion factors for the steel and the zirconia punches were determined separately and the punches were not removed from their holders throughout the study. Compaction data was captured using a computer data logging system, which enabled upper and lower punch forces, upper punch displacement and ejection forces to be recorded simultaneously using a PC. Corrections were made for each tooling distortion and machine effects.

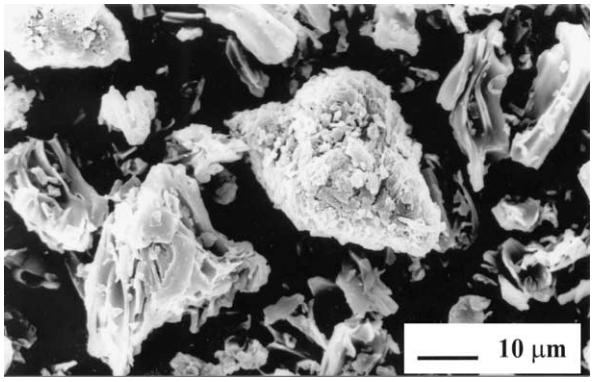

Fig. 2. A representative SEM micrograph of as-received magnesium stearate powder.

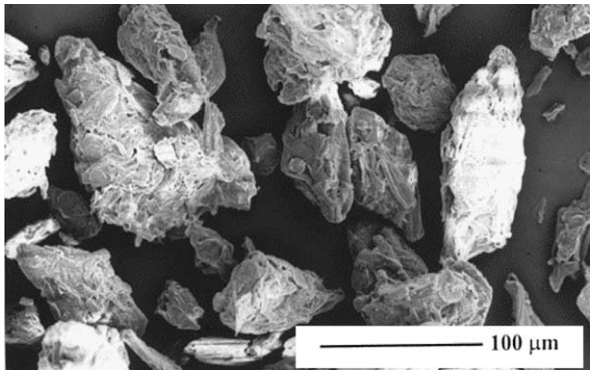

Fig. 3. A representative SEM micrograph of as-received Emcocel 90M powder.

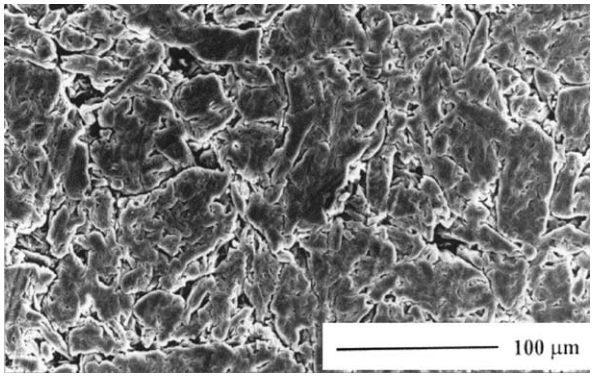

Fig. 4. A representative SEM micrograph of the upper surface of a tablet compressed from a mixture of Emcocel 90M with 0.5% magnesium stearate at 16 kN using zirconia tooling.

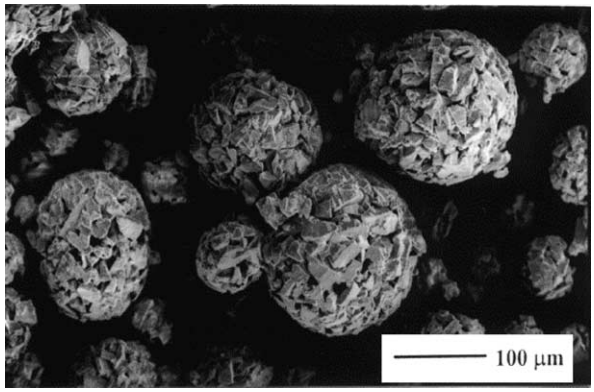

Fig. 5. A representative SEM micrograph of as-received Zeparox powder.

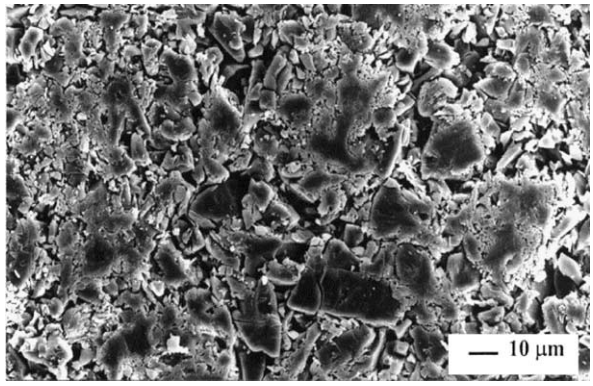

Fig. 6. A representative SEM micrograph of the upper surface of a tablet compressed from a mixture of Zeparox with 0.5% magnesium stearate at 20 kN using zirconia tooling.

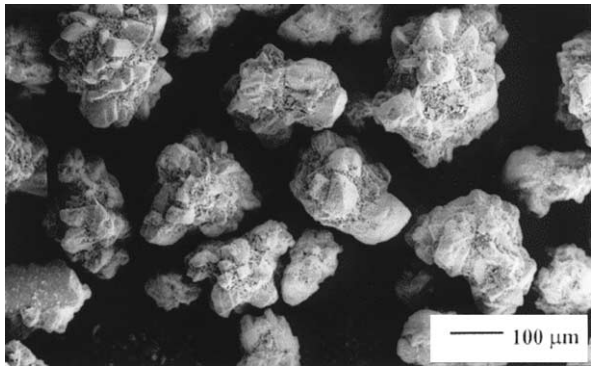

Fig. 7. A representative SEM micrograph of as-received Emcompress powder.

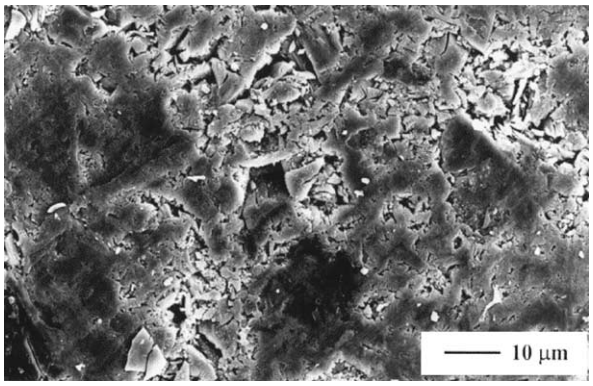

Fig. 8. A representative SEM micrograph of the upper surface of a tablet compressed from a mixture of Emcompress with 0.5% magnesium stearate at 25 kN using zirconia tooling.

The powders were compressed at five different compression forces ranging from 2 to 25 kN. These were 2, 4, 8, 12 and 16 kN for Emcocel 90M, 4, 8, 12, 16 and 20 kN for Zeparox, and 5, 10, 15, 20 and 25 kN for Emcompress. During tableting, the relative humidity (RH) varied from 35 to 45% and the room temperature from 20 to 25 °C. A series of about 10 tablets were made at each compaction pressure for each tooling set without any further adjustment of the equipment. The ejection force versus ejection time plots for at least 5 out of 10 tablets were constructed and averaged. The area under the each curve represents the work needed to overcome die wall friction during ejection. These areas were calculated by integration using Origin Version 4.1 software.

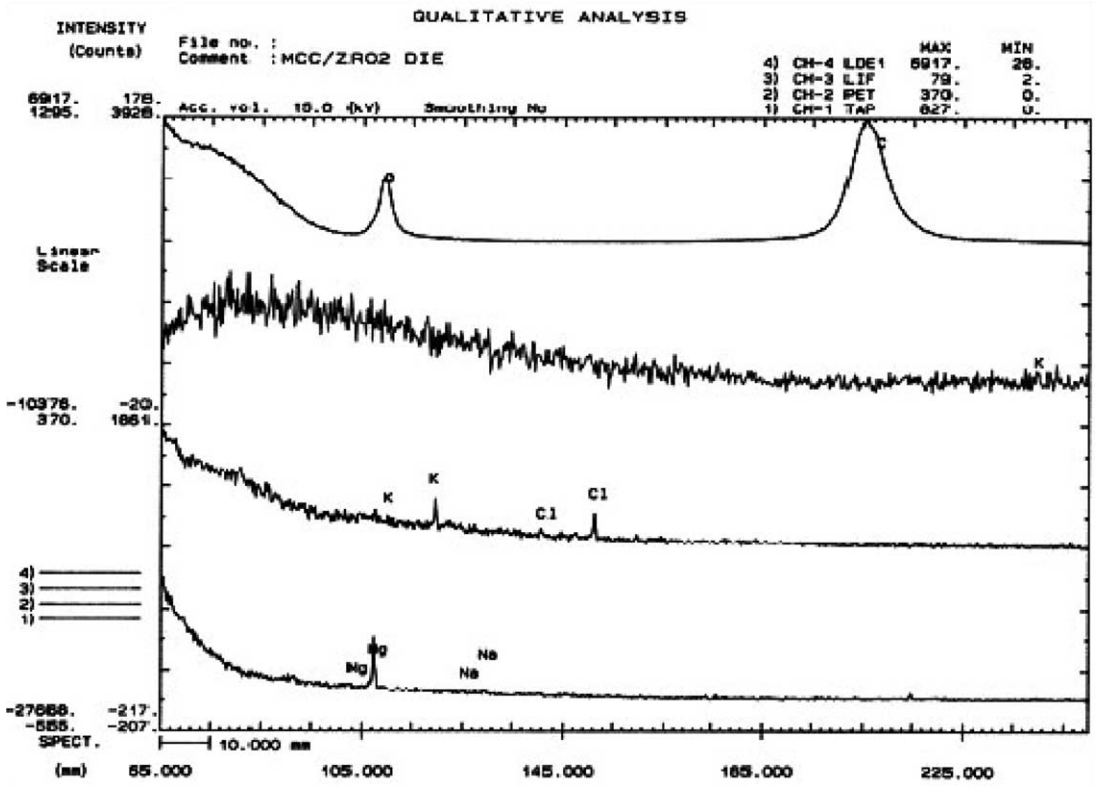

Fig. 9. A representative semi-quantitative EPMA analysis on the upper surface of a tablet compressed from a mixture of Emcocel 90M with 0.5% magnesium stearate at 16 kN using zirconia tooling.

Table 2
Compaction properties of Emcocel 90M determined at different compaction pressures using steel tooling/mean and standard deviation (in parentheses)

Compaction pressure (kN)	Tablet weight (mg)	Tablet thickness (mm)	Upper punch peak force (kN)	Lower punch peak force (kN)
2	306.6 (1.1)	4.08 (0.01)	2.019 (0.037)	1.922 (0.035)
4	306.2 (0.5)	3.35 (0.01)	4.061 (0.061)	3.844 (0.057)
8	305.2 (0.8)	2.87 (0.01)	8.139 (0.138)	7.656 (0.129)
12	305.8 (0.5)	2.76 (0.01)	12.039 (0.111)	11.319 (0.088)
16	306.6 (0.6)	2.72 (0.01)	16.232 (0.230)	15.348 (0.220)

Table 3
Compaction properties of Emcocel 90M determined at different compaction pressures using zirconia tooling/mean and standard deviation (in parentheses)

Compaction pressure (kN)	Tablet weight (mg)	Tablet thickness (mm)	Upper punch peak force (kN)	Lower punch peak force (kN)
2	306.2 (1.1)	3.81 (0.01)	2.049 (0.018)	1.956 (0.018)
4	306 (0.7)	3.20 (0.02)	4.044 (0.072)	3.846 (0.071)
8	306 (0.0)	2.88 (0.01)	8.071 (0.083)	7.673 (0.080)
12	306.2 (0.8)	2.77 (0.01)	11.971 (0.342)	11.419 (0.334)
16	306 (0.0)	2.72 (0.01)	16.285 (0.278)	15.672 (0.300)

Table 4
Comparison of the areas under the ejection force versus ejection time plots of Emcocel 90M determined at different compaction pressures using steel and zirconia tooling

Compaction pressure (kN)	Steel tooling	Zirconia tooling	% Reduction in the area under the ejection curve
2	3176.2	2374.9	25.2
4	3688.7	2543.5	31.1
8	2768.4	1563.0	43.5
12	1685.2	953.0	43.5
16	863.3	847.7	1.8

Table 7
Comparison of the areas under the ejection force versus ejection time plots of Zeparox determined at different compaction pressures using steel and zirconia tooling

Compaction pressure (kN)	Steel tooling	Zirconia tooling	% Reduction in the area under the ejection curve
4	4432.3	3696.0	16.6
8	9101.5	7662.4	15.8
12	12749.1	10885.5	14.6
16	16071.0	14438.9	10.2
20	19790.7	17847.7	9.8

Table 5
Compaction properties of Zeparox determined at different compaction pressures using steel tooling/mean and standard deviation (in parentheses)

Compaction pressure (kN)	Tablet weight (mg)	Tablet thickness (mm)	Upper punch peak force (kN)	Lower punch peak force (kN)
4	302.0 (0.0)	3.48 (0.01)	3.934 (0.039)	3.763 (0.032)
8	302.2 (0.5)	3.10 (0.1)	8.234 (0.117)	7.780 (0.109)
12	302 (0.7)	2.93 (0.01)	12.076 (0.144)	11.387 (0.138)
16	302.2 (0.8)	2.84 (0.02)	15.749 (0.397)	14.791 (0.387)
20	302.2 (1.1)	2.74 (0.02)	20.579 (0.559)	19.453 (0.464)

Table 6
Compaction properties of Zeparox determined at different compaction pressures using zirconia tooling/mean and standard deviation (in parentheses)

Compaction pressure (kN)	Tablet weight (mg)	Tablet thickness (mm)	Upper punch peak force (kN)	Lower punch peak force (kN)
4	302.0 (0.71)	3.47 (0.01)	3.897 (0.101)	3.656 (0.088)
8	301.6 (0.01)	3.12 (0.01)	8.151 (0.173)	7.556 (0.164)
12	301.8 (1.1)	2.95 (0.01)	12.027 (0.259)	11.119 (0.249)
16	302.0 (1.6)	2.84 (0.02)	15.936 (0.437)	14.772 (0.397)
20	301.6 (0.01)	2.76 (0.01)	20.637 (0.361)	19.282 (0.367)

3. Results and discussion

3.1. Electron microscopy

The material property that predominantly affects the tabletting of powders is the deformation behaviour of powder under stress. The deformation characteristics may be elastic, plastic, brittle fracture or a combination of these deformation mechanisms. Assessment of deformation behaviour and compressibility of powders can be investigated using a range of techniques including measurement of changes in bed density or porosity during compression, effect of punch velocity on compression, stress transmission during compression, work involved in compaction and compaction force versus time profiles.[11] Electron microscopy can also be employed for such assessment. Indeed, consolidation and bonding characteristics of different excipients mixed

with magnesium sterate have already been studied by scanning electron microscopy.[12,13] Scanning electron micrographs were also obtained in this study to investigate the lubricant and the excipients powders and compact surfaces for contrasting particle morphology before and after compaction. Representative low magnification images of magnesium stearate, Emcocel 90M, Zeparox and Emcompress particles are shown in Figs. 2, 3, 5 and 7, respectively. Figs. 4, 6 and 8 are also the SEM images showing upper surface details of the tablets compressed from the same powders using zirconia tooling. As can be seen from Fig. 4, in spite of the fact that the Emcocel 90M particles lost their pre-compaction shape and particle surfaces were joined together to a tight packing, the individual particles can still be easily distinguished, pointing to the non-occurrence of

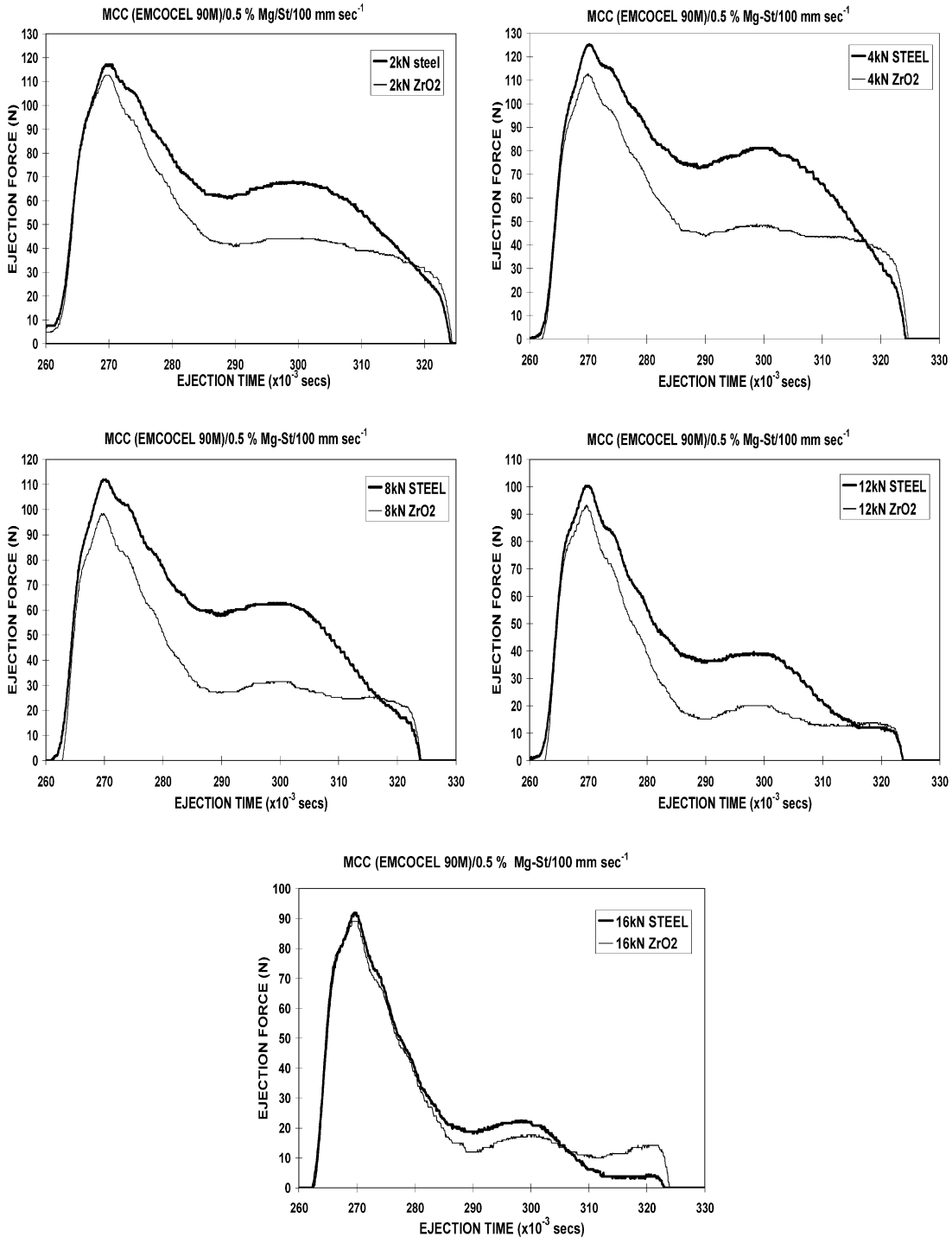

Fig. 10. Ejection force versus ejection time plots of Emcocel 90M determined at different compaction pressures using steel and zirconia tooling.

fragmentation. However, the somewhat "softer" character of the Zeparox and Emcompress agglomerated particles can be seen in the representative SEM images of their compact surface morphology in Figs. 6 and 8, respectively. Note that no considerable differences were observed on the surface details of the relevant tablets compacted using steel tooling.

EPMA was used to gain an insight into the possibility of contamination from zirconia tooling. In all cases, zirconia was absent on the surfaces of the representative tablets. Fig. 9 illustrates such a semi-quantitative EPMA analyses. The results were taken from a tablet compressed from a mixture of Emcocel 90M with 0.5% magnesium stearate at 16 kN using zirconia tooling. Only

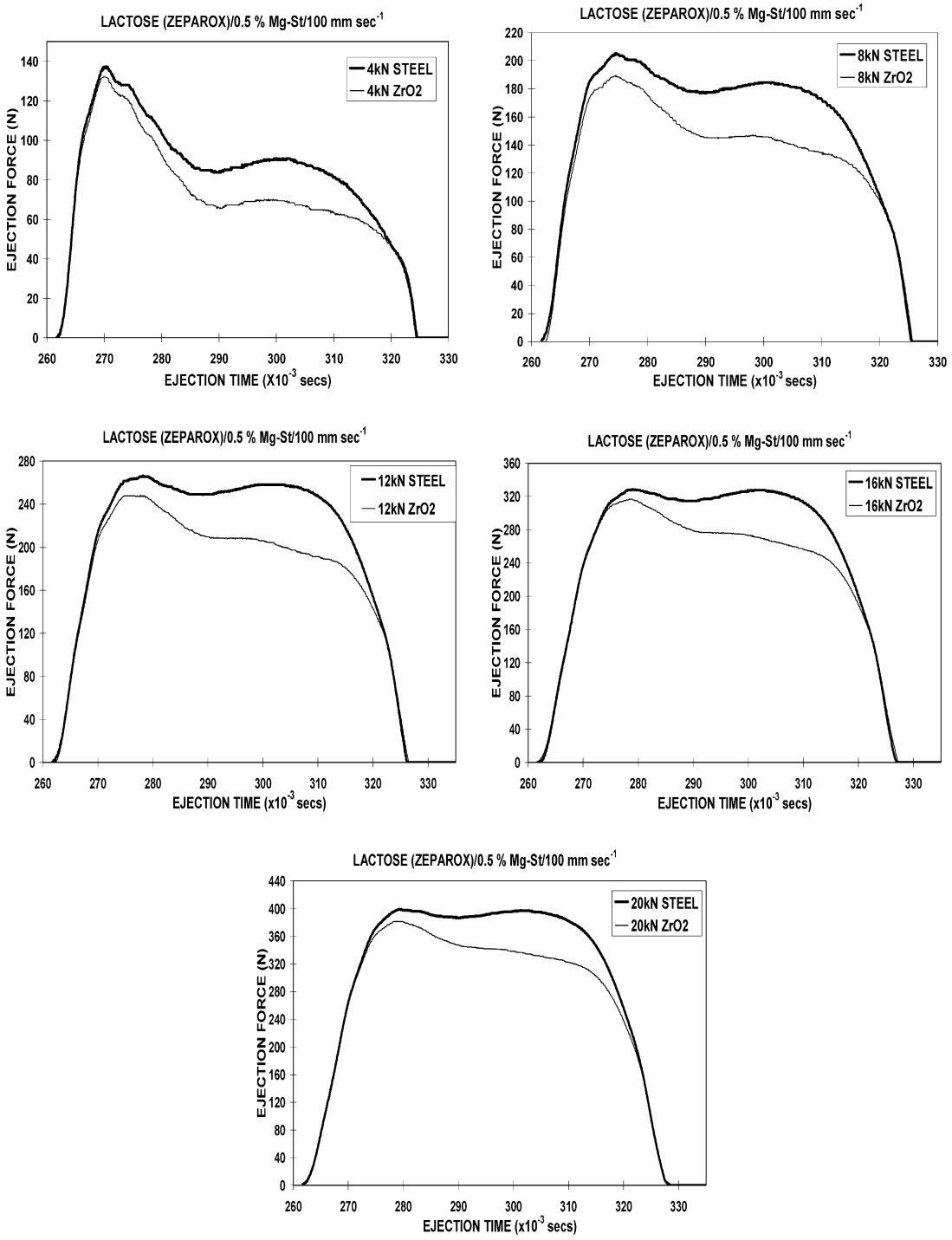

Fig. 11. Ejection force versus ejection time plots of Zeparox determined at different compaction pressures using steel and zirconia tooling.

the elements of magnesium (Mg), sodium (Na), potassium (K), chlorine (Cl), oxygen (O) and carbon (C) are seen on the analyses. Note that presence of minor amounts of Na, K and Cl is most probably due to contamination during handling of the tablet. In addition, C originated from the coating during specimen preparation.

3.2. Compaction characteristics

Tables 2–7 give the compaction properties of Emcocel 90M, Zeparox, and Emcompress determined at the relevant compaction pressures using steel and zirconia tooling. In addition, Figs. 10–12 illustrates the ejection force versus ejection time plots of the Emcocel 90M,

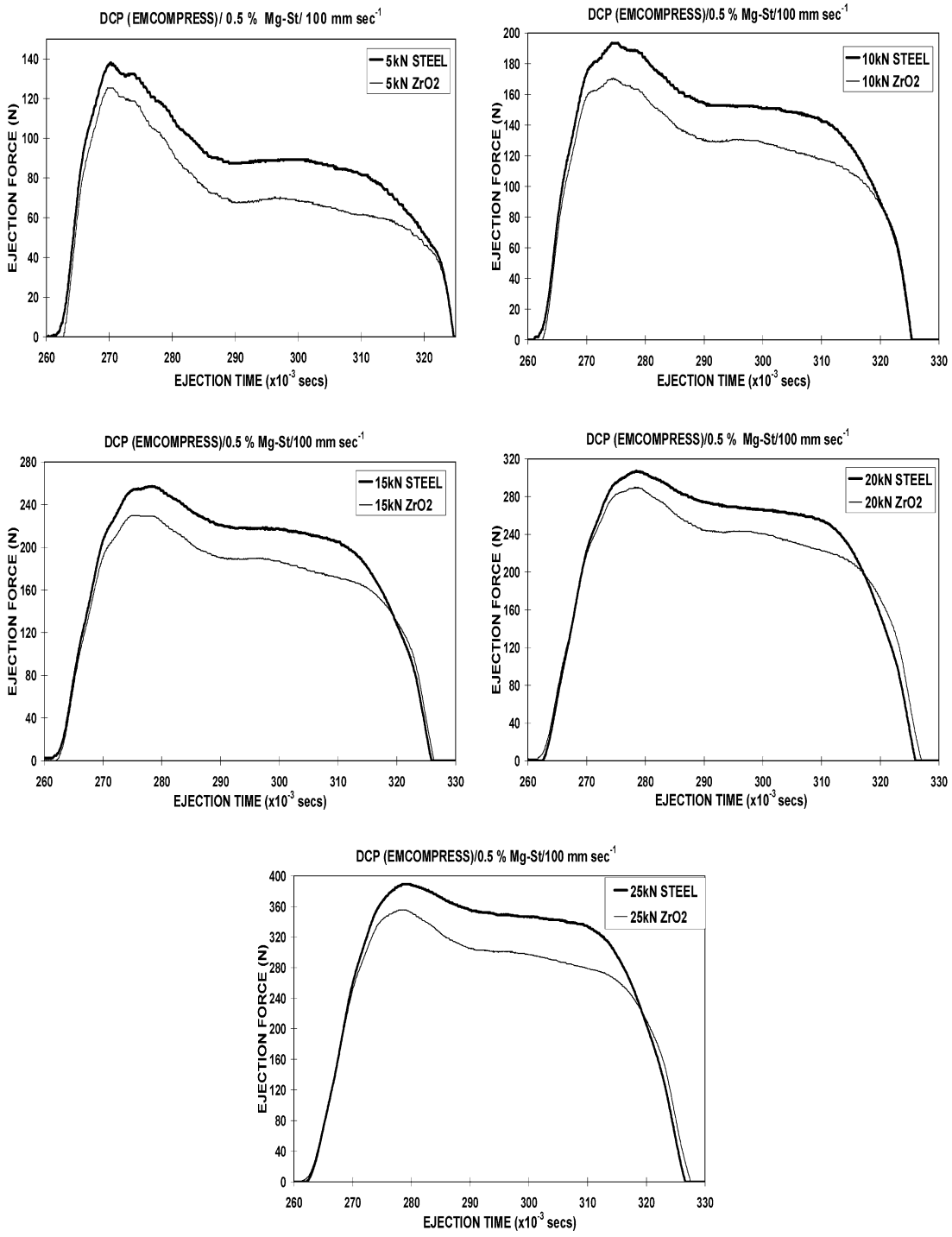

Fig. 12. Ejection force versus ejection time plots of Emcompress determined at different compaction pressures using steel and zirconia tooling.

Zeparox, and Emcompress, respectively, determined at relevant compaction pressures using steel and zirconia tooling. In each case, the upper line represents measurements made using steel tooling whilst the lower line represents measurements made using zirconia tooling. The representative plots obtained for the compacts ejected from steel and zirconia die almost follow the same profile. As the ejection stress is applied, a maximum is almost immediately reached at a maximum level (the static ejection stress), which corresponds to the first detectable compact movement relative to the die. The stress then decreases to a lower value (dynamic ejection stress), which remains relatively constant with respect to the displacement until the top or the bottom of the compact begins to emerge from the die. After this point, the ejection stress decreases almost linearly until the compact is completely out of the die. Such profile features have already been reported in the literature.[14] Another important observation on these plots is the fact that, apart from Emcocel 90M, as the applied compaction stress increases, the ejection stress increases. This is not surprising since a higher level of compaction stress produces higher radial and frictional forces at the die walls. During ejection these forces have to be overcome, and therefore the ejection force of a compact is higher for a pellet pressed to a greater applied compaction stress. The decrease in the ejection force with the increase in the compaction pressure for Emcocel 90M may, on the other hand, be explained, at least in part, to an overall reduction in the thickness of the resultant tablet (with lower area of contact with the ejection surfaces of the die). The figures show that zirconia tooling produce acceptably low ejection forces. This is of significance since the benefits of the advantageous frictional behaviour of zirconia tooling compared with steel tooling in the compaction of the relevant tablets at the added lubricant content are clearly apparent. The area under the each curve, calculated by integration, is given in Tables 8–10. As is also apparent from these tables, for each material, at each compaction force, there was a significant reduction in the amount of work in order to overcome the frictional forces during ejection for zirconia tooling. It s worth noting that there appeared to be a difference in the effectiveness between the effect on Emcocel 90M, being a plastically deforming material and Zeparox and Emcompress, being brittle fracture materials. The former showed a greater overall improvement in the % reduction in the area under the ejection curve (although the relative ejection forces are lower) compared with the latter materials. This phenomenon needs to be further examined to discover the reason for this mechanistic difference.

Table 10
Comparison of the area under the ejection force versus ejection time plots of Emcompress determined at different compaction pressures using steel and zirconia tooling

Compaction pressure (kN)	Steel tooling	Zirconia tooling	% Reduction in the area under the ejection curve
5	4576.4	3618.2	20.9
10	7909.7	6739.7	14.8
15	11222.5	9866.6	12.1
20	13609.4	12771.9	6.2
25	17746.2	15889.7	10.5

Table 8
Compaction properties of Emcompress determined at different compaction pressures using steel tooling /mean and standard deviation (in parentheses)

Compaction Pressure (kN)	Tablet weight (mg)	Tablet thickness (mm)	Upper punch peak force (kN)	Lower punch peak force (kN)
5	453.4 (0.6)	3.21 (0.6)	4.977 (0.084)	4.823 (0.066)
10	453.0 (0.7)	3.02 (0.01)	10.149 (0.072)	9.646 (0.070)
15	453.2 (0.5)	2.91 (0.01)	15.243 (0.102)	14.374 (0.095)
20	454.0 (0.0)	2.86 (0.01)	19.846 (0.121)	18.820 (0.175)
25	452.2 (0.5)	2.81 (0.01)	25.334 (0.134)	24.444 (0.130)

Table 9
Compaction properties of Emcompress determined at different compaction pressures using zirconia tooling /mean and standard deviation (in parentheses)

Compaction pressure (kN)	Tablet weight (mg)	Tablet thickness (mm)	Upper punch peak force (kN)	Lower punch peak force (kN)
5	453.0 (0.71)	3.20 (0.01)	5.270 (0.076)	5.013 (0.072)
10	453.2 (0.5)	3.03 (–)	10.044 (0.178)	9.394 (0.164)
15	453.2 (0.5)	2.91 (0.01)	15.126 (0.035)	14.151 (0.027)
20	453.3 (0.5)	2.86 (0.01)	19.982 (0.130)	18.981 (0.166)
25	453.0 (0.7)	2.81 (–)	25.446 (0.092)	24.684 (0.093)

4. Conclusion

From these results, the following conclusion may be drawn.

No evidence was found that zirconia was shed into any formulation. This was promising and as expected, as zirconia is considerably harder (Hv ~ 1300) than the materials being compacted; furthermore it is not known to be toxic on ingestion or inhalation.

The compaction properties of three commercially available direct compression excipients were examined over a range of compaction pressures using zirconia and steel tooling with the help of a compaction simulator. The ejection stress–time profiles were recorded at predetermined compaction loads and the area under each curve was measured and compared. The data obtained for all materials indicates that, for a particular compression speed, the work required to eject the tablet from the die, or in other words, the work needed to overcome die wall friction during ejection was lower for zirconia tooling than for conventional steel tooling. Operation of the compaction simulator enabled the demonstration of the advantages of the zirconia tooling. At the high speed employed in this study, significant reductions in ejection forces (as measured by area under the ejection force–time curves) were seen in all cases. It was noted that, in general, as the compaction forces increased there was a concomitant increase in observed ejection forces, except at the highest force, for the microcystalline cellulose. This aberration may be attributed to the relatively thin geometry of the compacts (with lower area of contact with the ejection surfaces of the die). The ejection force, calculated per unit contact area between the tablet and the die wall is recommended as a good measure of friction during tableting, but has the disadvantage that it depends on the compaction load.

The zirconia punches and die survived use in compaction simulator. This behaviour is considered sufficient to allay the fears of a large number of potential users of the technology that the dies would prove too fragile for general use. It is also considered that conventional steel tooling can be modified by addition of zirconia tips to the punches and a zirconia sleeve for the die itself. This modification is expected to allow the systems to be cheaper but also allows for much easier incorporation into tableting machines. In addition, steel outer case is believed to secure the zirconia insert and protect it during fitting and handling. The zirconia insert material is capable of resisting abrasion and chemical attack far better than steel. By shrink fitting the outer shell onto the insert a predetermined amount of compressive pre-stress can be introduced in the insert piece, thereby reducing the tensile stress in the die wall during tablet compaction.

In conclusion, it can be argued from the preliminary results presented in this paper that the deleterious action of lubricant such as magnesium stearate on the several properties of tablets can be counteracted by the use of zirconia tooling. However, it is suggested as a further work that a rigorous validation of the system be performed with the other excipients. Futher work is also needed in order to assess the physical properties of the tablets such as crushing strength, friability and disintegration time.

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