Compaction behaviour and mechanical strength of lactose-sodium starch glycolate and lactose-croscarmellose sodium binary tablets

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Abstract. The focus of this study is to elucidate the effects of adding super disintegrants (SSG and Acdisol) to a filler (lactose) in terms of the compaction behaviour and mechanical strength of the formed binary tablets. The tablets were formed in a uniaxial die compaction process with compaction pressures ranging from 37.7MPa to 150.7MPa. Consequently, the findings indicated that the increasing of the compaction pressure and the percentage mass composition of the super disintegrants would led to the increased in the strength of the tablets as well as their plastic energies, where this was more apparent for the case of the binary lactose/Acdisol tablets. In addition, as the compaction pressure increased, the maximum ejection pressure required to eject the tablet from the die cavity also increased. In contrast, a decreased in the maximum ejection pressure was observed as the composition of both super disintegrants increased in the lactose-super disintegrant binary tablets. In conclusion, the addition of super disintegrant; SSG with lactose and Acdisol with lactose; would enhanced the mechanical strength of lactose based tablets especially for the case of acdisol-lactose binary tablets in the experimental conditions adopted in this current work.

1. Introduction
Compaction of binary powder mixtures is an important area of research in the pharmaceutical tablet industries [1]. Tablets should be formulated in the correct proportion of active ingredients and excipients so that the tablet can disintegrate and dissolve at the right time and right place to release the drug in the human body [2]. Super disintegrants are added to decrease the dissolution time of tablets [3]. Two types of commonly used super disintegrants are sodium starch glycolate (SSG) and croscarmellose sodium (Acdisol) [3]. Apart from the intended purpose of increasing the spontaneity of the tablet dissolution, it will also inevitably affect the compaction behaviour during processing as well as the final tablet mechanical strength [4, 5]. The compaction behaviour such as the plastic deformation reflected in the calculated plastic energy under the force-displacement profile in the loading-unloading stages of the compaction process influences the final tablet mechanical integrity [6]. The final tablet mechanical integrity is important to ensure that the formed tablet can withstand the subsequent processing and handling throughout its lifetime before consumption by the end user. The ease of pushing or extruding the tablet from the die cavity is also important as a measure of the die wall friction between the tablet and the die wall, where low wall friction hence low maximum ejection forces are favoured in the compaction process to minimize wear and work [7].

Hence, in this current study, the effectiveness of the binary tablet was analyzed in terms of its compaction behaviour and mechanical strength characteristic. Lactose was chosen as the model filler excipient, where SSG and Acdisol super disintegrant powders were added individually to lactose powder to form a model binary tablet containing a filler and a super disintegrant.
2. Material and methods

2.1 Materials
A common pharmaceutical filler excipient; α-lactose monohydrate powder, and common super disintegrant agents; sodium starch glycolate and croscarmellose sodium were used in the making of the tablets. Lactose powders were received from Meggle Group Wasserburg, Germany, sodium starch glycolate (SSG) from Yung Zip Chemical Ind.CO., Taichung, Taiwan and croscarmellose sodium (Acdisol) from FMC Biopolymer, Philadelphia, USA.

2.2. Uniaxial die compaction process
The powders that have been received were sieved and only powders containing particles with sizes below 125 mm sieve size were used for tabletting. Lactose/SSG and and Lactose/Acdisol were mixed at different percentage of weight/weight of Lactose/SSG and Lactose/Acdisol which are 100/0 %, 80/20 %, 60/40 %, 40/60 %, 20/80 %, and 0/100%. 1.0g of the sieved powder was then compacted inside a 13mm stainless steel cylindrical uniaxial die (Specac, UK) at 37.7MPa, 75.4MPa, 113.0MPa and 150.7MPa compaction pressures using a universal testing machine (model 3382, Instron, Canton MA, U.S.A), therefore producing 1 g, 13mm diameter tablets. The cross head loading speed used was 0.1 mm/s and during the unloading stage was 0.0167 mm/s. The cross head speed during ejection was 0.1 mm/s.

2.3 Compaction behaviour analysis

2.3.1 Loading-unloading force displacement profile: plastic energy. The force-displacement profile is the force and displacement data recorded during compaction involving the loading and unloading of the force onto the powder bed inside the die. This profile can be used to investigate the behaviour of a powder during compression. The area under the force-displacement curve represented the work or energy involve during the compaction process. The plastic work represents the area constituted between the loading and unloading curves and yield a quantitative description regarding the plastic deformation of the powders during compression [4, 6, 8, 9, 10].

2.3.2 Ejection force displacement profile: maximum ejection pressure. The application of force in order to extrude the tablet out from the die cavity is due to the existence of the die wall friction. The ejection force-displacement profile is the force and displacement data recorded when the tablet is extruded or ejected from the die cavity. The maximum force recorded during this ejection stage is normally associated with the ‘static’ friction [11]. It is considered detrimental to the mechanical integrity of the tablet and increases the possibility of tablet damages occurring upon ejection from the die cavity [12].

2.4 Mechanical strength analysis
In order to measure the mechanical strength of the tablet, the indirect tensile strength method or Brazilian method was used. The test was conducted 24 hours after the tablet was formed. The tablet was place on its side and compressed using a universal testing machine (model 5566, Instron, Canton MA, USA) at a speed of 0.0116mm/s [10]. The load cell was then programmed to move down compressing the tablet until the tablet fracture diametrically. The indirect tensile strength of the tablet, $\sigma_t$, was calculated by using the equation [13]:

$$\sigma_t = \frac{2P}{\pi DT}$$

where $P$=breaking force
$D$= diameter of tablet
$t$= height of the tablet
The diameter and the thickness of the tablet were measured by using a digital vernier calliper (Mitutoyo, Japan).

3. Result and discussion

3.1 Plastic energy

Figure 1 illustrates that as the compaction pressure increased, the plastic energy of Lactose-SSG binary tablet increased. The highest plastic energy recorded was for pure SSG tablets formed at the highest compaction pressure of 150.7MPa, while the lowest was also for the pure SSG tablets. Similar to Lactose/SSG binary tablets, Lactose/Acdisol binary tablets also recorded a similar trend of increasing plastic energy with higher compaction pressure being used for tablet formation (Figure 2). The highest plastic energy recorded was for pure Acdisol tablet formed at 150.7MPa compaction pressure, while the lowest plastic energy is at 0% of Acdisol which is pure Lactose tablet formed at 37.7MPa compaction pressure.

Figure 1. Plastic energy of lactose-SSG binary tablets.
In general, from 0% to 40% composition of SSG, the trends show a rather constant plastic energy values (Figure 3). At further addition of SSG up to 80% composition resulted in a slightly higher plastic energy values at the higher compaction pressures of 113 MPa and 150.7 MPa. In contrast, slight reductions in the plastic energy values were observed at the lower compaction pressures of 37.7 MPa and 75.4 MPa. The addition of Acdisol increased the plastic energy as shown in Figure 4. Hence, it can be deduced that the addition of Acdisol increases the plastic energy during tablet formation more than the addition of SSG, based on the data observed in Figures 3-4.

**Figure 3.** Plastic energy of SSG tablets by composition of SSG.

**Figure 4.** Plastic Energy of Acdisol tablets by composition of Acdisol.

### 3.2 Maximum ejection pressure
After the loading-unloading stages, the application of force was needed in order to eject the tablet from the die. This stage is called the ejection stage. Based on Figure 5, pure Lactose tablets recorded the
highest maximum ejection pressure needed to remove the tablets from the die, especially at compaction pressures above the lowest compaction pressure of 37.7MPa. Low maximum ejection pressures were recorded for both pure Acdisol and SSG tablets, with no apparent dependency on the compaction pressures used during tablet formation.

Figure 5. Maximum ejection pressures for pure Lactose, SSG and Acdisol tablets at different compaction pressures.

The presence of resistance to motion of the tablet when it is pushed during ejection is due to its internal stored elastic energy when it undergoes compression in the loading stage of the compaction process [14]. A recompression of the already formed tablet during the ejection stage corresponding to this maximum ejection force has also been shown to occur [14] due to the internal stored elastic energy of the tablet. Hence, it can be deduced that pure Lactose tablets exhibited higher internal stored elastic energies at the start of the ejection stage, which increased when the compaction pressure increased. Meanwhile, the low maximum ejection pressures of Acdisol and SSG pure tablets reflected the low internal stored elastic energies possessed by them at the start of the ejection stage.

Figure 6 illustrates the decreased in the maximum ejection pressure with the increase in the SSG composition in the Lactose-SSG binary tablets. A similar trend could also be observed for the Lactose-Acdisol binary tablets maximum ejection pressure values as the composition of Acdisol added was increased (Figure 7).
3.3 Tablet mechanical strength

Based on Figure 8, the pure tablets having the highest mechanical integrity in terms of its tensile strength were pure Acdisol tablets, at all compaction pressures used in this work. Acdisol tablets displayed increasing tensile strengths in tandem with increasing compaction pressures used during the tablet formation. Meanwhile, pure lactose and SSG tablets exhibited apparently similar magnitude of low tensile strength values at lower compaction pressures of 37.7 MPa and 75.4 MPa. However, when the compaction pressure increased to 113 MPa and 150.7 MPa, pure Lactose tablets showed relatively higher tensile strength in comparison to pure SSG tablets. Hence, the tensile strength of pure SSG tablets can be regarded to be relatively uninfluenced by the range of compaction pressures used in this study.
Figure 8. Tensile strength of pure tablets at different compaction pressures.

The relationship between tensile strength and compaction pressure for Lactose-SSG and Lactose-Acdisol binary tablets could be observed in Figures 9-10. The influence of the compaction pressure on the tablet tensile strength was not apparent for Lactose-SSG binary tablets in comparison to Lactose-Acdisol binary tablets. In addition, the latter exhibited a clear dependency of its tensile strength on the compaction pressure, where higher compaction pressures produced mechanically stronger Lactose-Acdisol binary tablets. Furthermore, Lactose-Acdisol binary tablets possessed higher tensile strengths in comparison with Lactose-SSG binary tablets. This was due to the relatively higher plastic energies of Lactose-Acdisol binary tablets than Lactose-Acdisol binary tablets (Figures 1-4). Higher plastic energies provided a qualitative indication of stronger inter-particulate bondings due to higher plastic deformations enhancing bonding area (Shamsuddin et al. 2012; Zahraa et al. 2013; Mohammed et al. 2005). This in turn produced mechanically stronger tablets as for the case of Lactose-Acdisol binary tablets.

The addition of SSG to lactose did not affect much the tensile strength of the lactose-SSG tablets in comparison to the addition of Acdisol to lactose, as the latter increased the tensile strength of the lactose-Acdisol binary tablets especially at compaction pressures larger than 37.7 MPa (Figures 11-12).

Figure 9. Tensile strengths of lactose-SSG binary tablets at various compaction pressures.
Figure 10. Tensile strengths of lactose-Acdisol binary tablets at various compaction pressures.

Figure 11. Tensile strengths of lactose-SSG binary tablets at different compositions of SSG.
Figure 12. Tensile strength of lactose-Acdisol binary tablets at different composition of Acdisol.

4. Conclusion

The addition of super disintegrant to lactose affected the compaction behaviour as well as the mechanical strength of the formed binary tablets. The observed effects were dependent upon the compaction pressure used to form the tablets as well as the amount of super disintegrant used in making the binary tablets. The increased in the compaction pressure and the percentage mass composition of the super disintegrants would led to the increased in the strength of the tablets as well as their plastic energies, where this was more apparent for the case of the binary lactose/Acdisol tablets. Also, the maximum ejection pressure required to eject the tablet from the die cavity also increased in tandem with the increasing compaction pressure used in the study. In contrast, a decreased in the maximum ejection pressure was observed as the composition of both super disintegrants increased in the lactose-super disintegrant binary tablets. In conclusion, the addition of super disintegrant; SSG with lactose and Acdisol with lactose; would enhanced the mechanical strength of lactose based tablets especially for the case of acdisol-lactose binary tablets in the experimental conditions adopted in this current work.

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