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The effects of lubrication on the compaction and post-compaction properties of directly compressible maltodextrins

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Abstract

The effects of various concentrations of magnesium stearate as a tablet lubricant on three types of maltodextrins were investigated. The maltodextrins were physically processed by the methods of spray drying, fluidized bed agglomeration, and roller compaction were compared for their compaction and post-compaction properties. The compaction tests were performed using a 10.3 mm round tooling in conjunction with an Integrated Compaction Research System operating at a constant punch velocity of 100 mm/s. The lubricant sensitivity of the materials were determined using the R values (i.e. the ratio of the maximum lower punch force to the maximum upper punch force). The R values for the compacts of all types of maltodextrin reached a plateau when the magnesium stearate concentration was 0.5% (w/w) or higher. The compaction properties of the materials were studied by using the total work of compaction (TWC) and average power consumption (APC) parameters, both of which decreased with an increase in lubricant concentration due to decreased particle cohesiveness. The compaction time data, which were analyzed by dividing the compaction period into four regions, exhibited correlations with the TWC and APC values. The crushing strength of the compacts exhibited a decrease as the lubricant concentration was increased, which was in agreement with the TWC and APC data. The compacts of the maltodextrins generally experienced increased tablet porosity with an increase in lubrication concentration with the exception of one type of maltodextrin which was processed by the roller compaction method. The compacts of the latter were also stronger and less sensitive to lubrication than those of the other maltodextrins examined. In this study, dicalcium phosphate, which is a lubrication insensitive material, was also used as a 'reference material'.

Keywords: Compaction; Lubrication; Maltodextrin; Excipient; Magnesium stearate; Direct compression; Integrated compaction research system (ICRS)

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1. Introduction

The maltodextrins are starch conversion products which are currently available as potential direct compression filler/binder excipients. Parrott (1989) evaluated the maltodextrin, Soludex 15, and examined mixtures of the maltodextrin with magnesium stearate. He observed decreased tablet strength with increased magnesium stearate concentration however, tablets of acceptable strength could be produced with 0.5% magnesium stearate concentration. Papadimitriou et al. (1992) evaluated Maltrin M500 and found a strong retardant effect on drug release when mixed with a water insoluble substance, and that the retardant effect increased with the concentration of magnesium stearate in the mixture. The retardant effect was not exhibited with mixtures containing a water soluble drug substance.

The effect of magnesium stearate as a tablet lubricant and its effect on tablet properties has been well researched since the 1950s with the work by Nelson et al. (1954) and Strickland et al. (1956). Nelson developed the '*R* value' as a measure of the efficiency of a lubricant. The *R* value represents the ratio of the maximum lower punch force to the maximum upper punch force. Strickland indicated that lubricants seemed to form a coating around individual granules, and for the materials examined this coating appeared to remain more or less intact during the compression process. Bolhuis et al. (1975) examined mixtures of a number of excipients with magnesium stearate as a tablet lubricant and stated that the starch products, which deform plastically under compression, exhibited almost a maximum reduction in tablet crushing strength. In contrast, the binding properties of dicalcium phosphate dihydrate were completely unaffected by the presence of magnesium stearate. A reduction in tablet crushing strength with lubrication level was thus found to be dependent upon the physical nature of the base material. DeBoer et al. (1978) found that magnesium stearate exercised a maximum effect on excipients that undergo complete plastic deformation without any fragmentation under compression and were bonded by cohesion, such as starch and some starch derivatives. The bonding properties of excipients which underwent complete fragmentation under pressure were practically uninfluenced by magnesium stearate. More recent work by Riepma et al. (1993) described that magnesium stearate sensitivity of brittle materials may not be directly related to the degree of particle fragmentation on compression, but was primarily determined by the degree of coating on the excipient by lubricant from the dry mixing operation.

2. Methods and materials

The maltodextrins used were: Maltrin M510 (Lot # A3533), Dextrose Equivalent = 9–12, which is a spray dried product, and Maltrin M500 (Lot # 094906), Dextrose Equivalent = 9–12, which is a fluidized bed agglomerated product, both by Grain Processing Co; Malta*Gran TG (Lot # A1009), Dextrose Equivalent = 10, and Malta*Gran 10 (Lot # A1500), Dextrose Equivalent = 10, which are fluidized bed agglomerated products by Zumbro/IFP; and Experimental Maltodextrin (Lot # I2169X), Dextrose Equivalent = 15, which is a roller compacted material by Edward Mendell. Experimental Maltodextrin is not yet a marketed product, and its mean particle size is yet to be determined. Therefore, in this study sieve cuts of Experimental Maltodextrin with a theoretical mean particle size of 182 μm were used for all testing since this was the target size for the final marketed product (Mollan and Çelik, 1993). The reference filler/binder excipient used for comparison in the study was dibasic calcium phosphate dihydrate, USP, (Emcompress), (Lot # 3083X) by Edward Mendell. Magnesium Stearate N.F., (Lot # 2256KCCA) by Mallinckrodt was used as the lubricant for the study.

All materials were used as received, with the exception of magnesium stearate which was prescreened through a 250 micron (60 mesh) screen to minimize agglomeration. The concentration of magnesium stearate used was 0.00, 0.10, 0.50, 1.00, and 2.00% of the mixture. The exception to this was the compaction of Emcompress at 0.00 and 0.10% lubrication level. Tablets made from

this material at these magnesium stearate concentration levels could not be ejected intact from the die, and for this reason a 5% magnesium stearate in acetone suspension was coated over the punches and die wall prior to each compaction event. The mixtures were all blended in a Turbula T2C mixer (Glen Mills, NJ) for 2 min. Humidity control was achieved by storing the materials in desiccators above saturated salt solutions of magnesium nitrate which maintained a 52.8% relative humidity, as per Nyqvist (1983). The effect of storage conditions for maltodextrins has been previously reported by Mollan and Çelik (1995).

The true densities were determined for the materials alone (helium pycnometry by Multipycnometer, Quantachrome, Syossett, NY), and for the lubricated mixtures.

Surface area measurements were performed by the nitrogen adsorption multipoint BET method in the relative pressure range of 0.05–0.35 (Quantasorb Sorption System, Quantachrome, Syosset, NY). The powders were vacuum dried for 6 h at 60°C, then degassed with nitrogen for a minimum of 1 h prior to testing.

The powders were compacted into tablets employing an Integrated Compaction Research System (Mand Testing, Stourbridge UK) which utilized a 'sawtooth', i.e. constant velocity waveform, of double ended design operating at a punch velocity of 100 mm/s. This type of profile was chosen because it allowed all of the formulations to be subjected to the same punch velocity during the compaction event, without the need to adjust the punch profiles for each mixture due to variations in the bulk densities. A standard flat-faced round 10.3 mm set of BB tooling was used. Comparison between formulations were made with the amount of powder compacted as 0.2 cm^3 in constant true volume at 0% porosity. The deformation of the system, i.e. punches, load cells, and other components in linear series with the punches, was accounted for by a 'punch on punch' method. Deformation of the upper and lower punch was determined up to 40 kN, and these values then fitted to polynomial equations which best described the phenomena. These equations were then used to compensate for system deformation in order to obtain accurate displacement measurements during compaction testing. Ejection forces were not measured in this study due to the insufficient resolution of the load cell signals at the time of the investigations. In-die data reported are the mean of three individual tablet compactions. The tablets were made by compaction to 75 and 300 MPa mean pressure for comparison purposes.

The physical testing of the tablets was performed 24 h after ejection to allow for viscoelastic expansion. The physical measurements and tests included: weight (model 100A XE series, Denver Instrument, Arada, CO); compact thickness and diameter, by micrometer (Material Control, Pennsauken, NJ), and crushing force (VK 2000, VanKel, Edison, NJ). Reported tablet crushing force and ejected tablet porosity data are a mean of ten determinations.

3. Results and discussion

3.1. During compaction, in-die testing

The results of the compaction data evaluation by the R value method are shown in Table 1. The level of magnesium stearate in the mixture had a very significant effect on the R value, with the expected results of increased R values occurring with increased lubricant at both pressure levels examined. The R value for the compacts of all the materials began to plateau after a magnesium stearate concentration of 0.5% loading level. The R values were closer to unity when the pressure applied was higher (300 MPa), and indicated increased efficiency of magnesium stearate as a tablet lubricant at higher pressures. This effect has been previously shown by Fukumori and Carstensen (1983) with frictional coefficients. Since it is expected that there is less surface area at higher pressure compared with lower pressure, therefore less magnesium stearate is required to cover the surface and provide lubrication. The same type of trend is shown in this work with magnesium stearate lubricant effect as evaluated by the R value.

The energy transferred by the upper and lower punches to the powder bed is utilized for particle

Table 1
The R, TWC, APC, T_{ct}, T_{mx}, T_{em}, T_{et} values of the compacts made at 75 MPa and 300 MPa maximum pressure

Excipient	Lubricant level (%)	Maximum pressure = 75							Maximum pressure = 300						
		R	TWC (J)	APC (W)	T_{ct} (ms)	T_{mx} (ms)	T_{em} (ms)	T_{et} (ms)	R	TWC (J)	APC (W)	T_{ct} (ms)	T_{mx} (ms)	T_{em} (ms)	T_{et} (ms)
Experimental Maltodextrin	0.0	0.760	3.08	85	38	35	15	19	0.850	9.03	191	52	43	24	33
	0.1	0.900	2.93	80	38	34	15	19	0.897	8.30	179	52	43	24	34
	0.5	0.939	3.06	84	38	34	15	19	0.944	7.78	164	52	43	24	33
	1.0	0.946	2.83	76	39	35	15	19	0.951	8.00	159	53	43	23	33
	2.0	0.945	2.96	79	38	35	15	18	0.958	7.44	153	53	43	23	33
Maltrin M510	0.0	0.856	4.99	138	38	34	22	27	0.859	12.19	248	53	43	32	41
	0.1	0.867	4.98	138	38	34	22	26	0.925	11.74	246	52	42	32	41
	0.5	0.934	4.89	142	36	31	21	26	0.948	11.53	242	50	41	31	40
	1.0	0.937	4.46	134	35	30	20	25	0.959	10.90	236	49	40	30	39
	2.0	0.940	4.28	131	34	29	19	23	0.967	9.55	211	48	38	28	37
Maltrin M500	0.0	0.830	5.87	77	81	77	29	33	0.855	12.17	140	95	86	39	48
	0.1	0.907	5.86	75	80	76	27	31	0.939	11.34	130	94	85	37	46
	0.5	0.931	5.63	74	79	74	27	32	0.955	11.38	131	93	84	37	46
	1.0	0.937	5.44	72	79	74	25	30	0.960	11.23	130	93	83	36	45
	2.0	0.938	5.07	69	76	72	25	29	0.966	10.03	118	90	81	33	42
Malta*Gran TG	0.0	0.862	4.92	97	54	50	24	28	0.853	12.07	194	69	59	33	43
	0.1	0.902	5.15	104	51	47	23	28	0.933	11.44	184	66	56	33	42
	0.5	0.937	4.84	101	50	46	22	27	0.954	10.82	176	65	55	32	42
	1.0	0.940	4.68	102	48	44	22	26	0.960	10.53	180	63	53	32	41
	2.0	0.942	4.33	99	46	41	21	26	0.967	9.72	174	60	50	31	41

Table 1 (continued)

Excipient	Lubricant level (%)	Maximum pressure = 75							Maximum pressure = 300						
		R	TWC (J)	APC (W)	T_{et} (ms)	T_{mx} (ms)	T_{em} (ms)	T_{et} (ms)	R	TWC (J)	APC (W)	T_{et} (ms)	T_{mx} (ms)	T_{em} (ms)	T_{et} (ms)
Malta*Gran 10	0.0	0.859	5.29	77	72	68	27	31	0.867	12.11	148	87	77	38	48
	0.1	0.915	5.64	84	71	67	27	31	0.948	11.28	141	86	76	36	46
	0.5	0.936	5.60	86	68	63	27	31	0.965	10.53	138	82	73	36	46
	1.0	0.940	5.10	79	67	62	25	30	0.971	10.42	136	81	72	35	45
	2.0	0.945	5.25	84	66	61	25	29	0.973	9.77	132	80	70	35	44
Emcompress	0.0	0.891	3.54	124	30	27	20	23	0.884	7.98	218	44	35	28	37
	0.1	0.733	3.74	129	29	26	19	22	0.778	8.19	229	44	35	28	38
	0.5	0.943	3.61	120	30	27	20	23	0.940	7.79	207	44	35	28	37
	1.0	0.940	3.52	118	30	27	19	23	0.944	7.40	200	44	35	27	36
	2.0	0.942	3.35	112	30	27	19	22	0.948	7.08	194	44	35	27	36

Table 2
The mean particle size, specific surface area, and bulk density data of the maltodextrins studied

Maltodextrin	Mean particle size (μm)	Specific surface area (m^2/g)	Bulk density (g/cm^3)
Experimental Maltodextrin	179	1.73	0.57
Maltrin M510	104	0.31	0.50
Maltrin M500	260	0.54	0.27
Malta*Gran TG	318	0.40	0.38
Malta*Gran 10	285	0.50	0.29

rearrangement, elastic-plastic deformation, and/or brittle fracture as well as for the formation of new bonds within the tablet matrix. The total work of compaction (TWC) can be calculated as per Çelik and Marshall (1989):

$$\mathrm{TWC} = \left(\int_{x=0}^{x_{\max(\mathrm{up})}} F_{\mathrm{up}} \times \mathrm{d}X_{\mathrm{up}} \right) + \left(\int_{x=0}^{x_{\max(\mathrm{lp})}} F_{\mathrm{lp}} \times \mathrm{d}X_{\mathrm{lp}} \right)$$

where F_{up} and F_{lp} are the forces on the upper and lower punches respectively; X_{up} and X_{lp} are the contribution of the upper and lower punches, respectively to the decrease in the distance between them; $X = 0$ is the point where the porosity equals the initial porosity, and the maximum applied load was reached at $X_{\max(\mathrm{up})}$ and $X_{\max(\mathrm{lp})}$. The higher the work input involved during the compaction of a powder system, the stronger the compact is expected to be formed due to the higher amount of energy utilized in the formation of bonds, provided that die wall friction is minimal. If a time element is used in conjunction with the force and displacement data, then the power utilized during the compaction of a powder system can be calculated. Several methods of determining power have been reported, and this study utilized the average power consumption (APC) method (Çelik and Marshall, 1989).

The results of testing and the calculated values of TWC and APC at maximum pressure are shown in Table 1. The trend of decreasing TWC and APC values with an increase in lubricant level is clearly seen at the 300 MPa pressure. The data at 75 MPa pressure shows no distinctive trend for any of the materials. The TWC and APC values obtained at each set of conditions complemented each other due to the constant velocity waveform which was used in the study. Decrease in the TWC and APC values with lubricant level was due to a decreased degree of cohesiveness between the particles as well as decreased frictional effects at the punch faces and die wall. The area under the force displacement curve then decreased because less work was needed to achieve an equivalent mean pressure.

The time period over which the compaction event has occurred can be divided into a number of different regions which can be of use as part of the complete evaluation of in-die compaction data. In this study, the compaction event has been divided into the following four separate time periods of interest which were extracted from the data; T_{ct}, T_{mx}, T_{em}, and T_{et}. The period, T_{ct}, is the contact time, and is the time period from when the punch initially contacts the powder bed, as determined from fill height, until the time when the punch loses contact with the formed tablet, as determined from the force data and specified at 100 N due to force transducer resolution. The period, T_{mx}, is the time to maximum force, and is the time period from when the punch initially contacts the powder bed, until the time when maximum force is achieved. The period, T_{em}, is the effective time to maximum force, and is the time period from when a force level is initially determined, which is found by an averaging technique with a precision of 100 N, until the time when maximum force is achieved. The period, T_{et}, is the total effective time, and is the time period from when a force level initially is determined, as described above, until the time when the upper punch loses contact with the formed tablet, defined as 100 N.

The time data from the compaction events are also shown in Table 1. The bulk density of the materials are shown in Table 2. The contact time, T_{ct}, generally corresponded to the bulk density of the material, with low bulk density materials having intrinsically longer contact times. The time to maximum force, T_{mx}, also followed this trend. Increased levels of magnesium stearate caused increases in the bulk density, and this was illustrated by changes in the time values, T_{ct} and T_{mx}, of the low density materials. All the time period values decreased due to increased particle efficiency in rearranging in the die during compression. Maltrin M500, Malta*Gran TG, and Malta*Gran 10 all had relatively low initial bulk densities and their time period values all continued to decrease with increased magnesium stearate level. The time period data did not show the plateau effect with magnesium stearate level as was seen with the R value data. Instead the time period data correlated with the changes which were seen in the TWC and APC values. The methods of TWC, APC, and compaction time period evaluation were more sensitive in-die methods of determining the effect of lubrication level on the compaction phenomena than simply using the R value. The higher bulk density of Experimental maltodextrin and Emcompress did not show much effect in their time period data due to lubrication level.

3.2. Post-compaction, out of die testing

Fig. 1 is a plot of tablet crushing force vs magnesium stearate level in the blend for the maltodextrins tested and Emcompress, as reference material, at mean compaction pressure of 75 MPa while Fig. 2 is a similar plot but at 300 MPa maximum pressure. The two profiles depict analogous results, with differences seen between the behavior of Emcompress and the maltodextrins. Emcompress shows no change in tablet crushing force with lubricant level, which agrees with the results of Bolhuis et al. (1975). All the maltodextrins behaved similarly to each other, with decreased tablet crushing force with increased lubricant level occurring at both pressures. Experimental maltodextrin exhibited the smallest crushing force decrease with lubrication level of the maltodextrins examined. This lower sensitivity to magnesium stearate is considered primarily to be due to the surface area and deformation behavior of the roller compacted material. The specific surface area, mean particle size, and bulk density values of the maltodextrins are reported in Table 2. Experimental maltodextrin had a much larger surface area than the other maltodextrins, therefore the total lubricant film formation should be less than the other maltodextrins. The roller compacted maltodextrin failed more by fragmentation during the compaction event, than the other more plastically deforming maltodextrins as previously reported by Mollan and Çelik (1993); this type of brittle failure then generates new clean surfaces which would be available for bonding. All the other maltodextrins failed primarily by plastic deformation, and once the surfaces of the materials were coated with lubricant film, no new clean surfaces would be available for bonding. This leads to a decrease in tablet crushing force. The similar behavior of the roller compacted maltodextrin and dicalcium

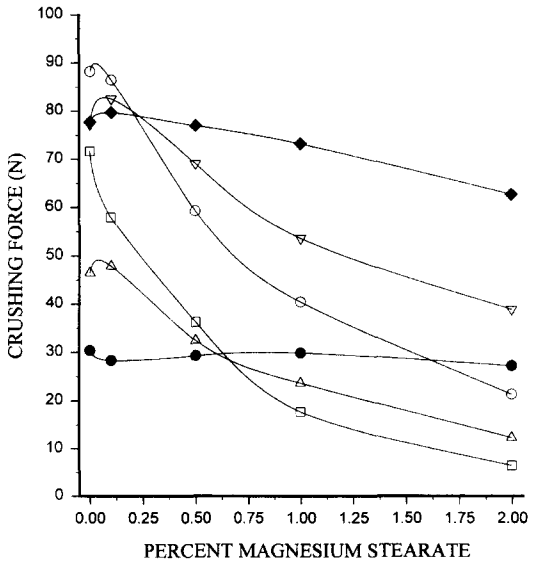

Fig. 1. Tablet crushing force vs magnesium stearate concentration (w/w) plots of the compacts made at 75 MPa applied pressure, (□) Maltrin M510; (○) Maltrin M500; (△) Malta*Gran TG; (▽) Malta*Gran10; (◆) Experimental Maltodextrin; (●) Emcompress.

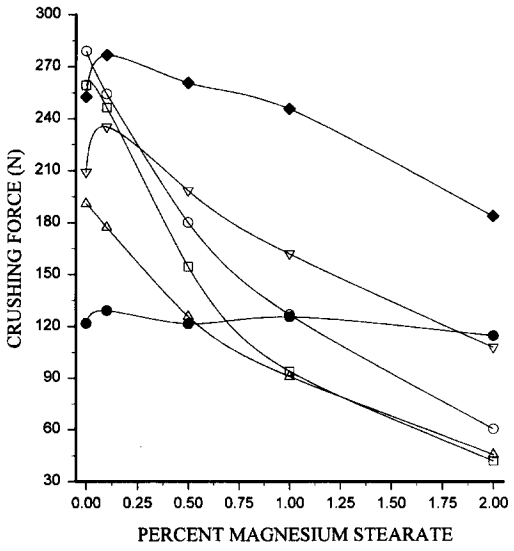

Fig. 2. Tablet crushing force vs magnesium stearate concentration (w/w) plots of the compacts made at 300 MPa applied pressure, (□) Maltrin M510; (○) Maltrin M500; (△) Malta*Gran TG; (▽) Malta*Gran10; (◇) Experimental Maltodextrin; (●)Emcompress.

phosphate dihydrate with regard to failure properties was also seen in the time period data evaluation shown in Table 1.

Fig. 3 is a plot of ejected tablet porosity vs percentage of magnesium stearate in the blend for the maltodextrins tested and Emcompress at a mean compaction pressure of 75 MPa, while Fig. 4 is the similar plot at 300 MPa maximum pressure. Emcompress showed very little change in porosity with magnesium stearate loading level which agreed with the insensitivity to magnesium stearate concentration for the tablet crushing force results which are illustrated in Figs. 1 and 2. Experimental maltodextrin showed only a slight change in tablet porosity with magnesium stearate concentration which corresponded with the limited loss in tablet crushing force which is seen in Figs. 1 and 2. All the other maltodextrins experienced increased tablet porosity with increased magnesium stearate concentration. This behavior correlated with the losses in tablet crushing force depicted in Figs. 1 and 2. This behavior was due to the magnesium stearate coating on the particles which were then unable to bond because of the lubricant film. On decompression, the two surfaces separated due to lack of an adequate bond thus causing an increase in tablet porosity.

4. Conclusions

The R value for all the compacts of maltodextrins began to plateau after a magnesium stearate concentration of 0.5% loading level. The calculated TWC and APC values obtained at 300 MPa pressure level compactions decreased with increased lubricant level.

Time data evaluation of the compaction event was useful for characterizing a material's rearranging efficiency in the die. The time period data corresponded with the bulk density of the materials. The time period data evaluation also correlated with the material's failure properties under compression.

The roller compacted maltodextrin was more robust to increased magnesium stearate concentrations than were the other maltodextrins, as evaluated from tablet crushing force. This was

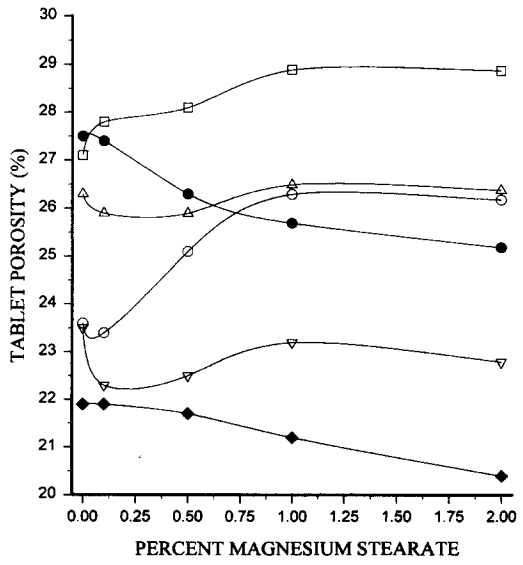

Fig. 3. Ejected tablet porosity (%) vs magnesium stearate concentration (w/w) plots of the compacts made at 75 MPa applied pressure, (□) Maltrin M510; (○) Maltrin M500; (△) Malta*Gran TG; (▽) Malta*Gran10; (◇) Experimental Maltodextrin; (●)Emcompress.

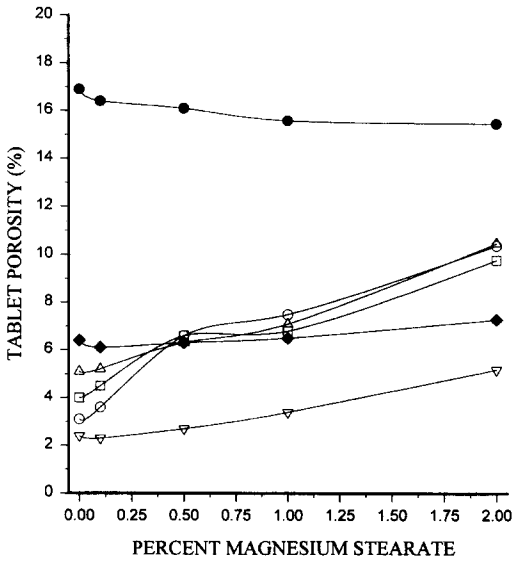

Fig. 4. Ejected tablet porosity (%) vs magnesium stearate concentration (w/w) plots of the compacts made at 300 MPa applied pressure. (□) Maltrin M510; (○) Maltrin M500; (△) Malta*Gran TG; (▽) Malta*Gran10; (◇) Experimental Maltodextrin; (●) Emcompress.

due to a large surface area, high bulk density, and more fragmentary failure behavior for the roller compacted maltodextrin as compared with the other maltodextrins studied. Tablet porosity data correlated well with the tablet crushing force data.

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