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Evaluation of Affinisol® HPMC polymers for direct compression process applications

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ABSTRACT

Affinisol® (Hydroxypropylmethyl cellulose) polymers with low glass-transition temperature are usually processed by Melt Extrusion and show better compressibility at lower compression pressure. This study evaluates the compaction properties and powder properties of Affinisol® Powder by the determination of physical properties like bulk/tapped density, angle of repose and loss on drying, an out-of-die compactability, axial expansion post-compression, effect of compression force on hardness of the compact, friability and lubricant sensitivity. The results of the evaluation of powder properties showed that the tested polymers had acceptable flow properties and low moisture content and lower yield pressure. This is evident by higher hardness of compact at lower compression pressure (up to 66 MPa) compared to HPMC E15. The friability of Affinisol® tablets was much lower than HPMC E15 tablets. The plastic nature of the polymers caused more than 30% loss of compressibility due to lubrication. Differential Scanning Calorimetry studies confirmed low glass transition temperature of the polymers, which can be attributed to other higher degree of substitution. Overall, Affinisol® HPMC polymers can be proposed as a binder or controlled release matrix former for direct compression.

1. Introduction

Direct compression is the most desirable process for tablet manufacturing in terms of time and economy. Other advantages in comparison to wet granulation include suitability to process moisture and/or heat sensitive Active Pharmaceutical Ingredients (API) and excipients for aqueous wet granulation, or improvement on the safety and environmental aspects for non-aqueous wet granulation. Since direct compression does not involve any type of granulation (wet or dry) that improves flow and compression property, the compression properties of the final blend is a function of the individual excipients and their physical mixture. Therefore, in order to produce tablets using direct compression process, it is imperative to understand the mechanical properties of the material. Tableting properties of pharmaceutical excipients comprise of compressibility and compactibility. “Compressibility” is the ability of a material to deform or decrease in volume on application of pressure, whereas “compactibility” refers to material's ability to be compressed into a compact of specified mechanical strength [1].

Hydroxypropylmethyl cellulose (HPMC) is a versatile excipient that is used as binder in wet granulation, dry binder, hydrophilic matrix polymer, maintaining supersaturation or preventing precipitation of API [2,3]. HPMC has been used to form hydrophilic matrix in tablet dosage form for extended release systems; however, higher molecular weight grades of HPMC have been shown to be harder, less plastic and require higher pressures to deform compared to their low molecular weight counterparts [4]. Picker demonstrated the importance of the glass transition temperature (T_g) in the compaction process and proposed that there would be an improved deformation with an improved particulate bonding surface ensuing a higher strength of compact, if the T_g was exceeded reversibly during compaction [5]. It was suggested that this would occur for HPMC at high compaction densities but not at low compaction densities since insufficient heat is produced during compaction at lower compaction pressures [5]. Hardy et al. showed the improvement in compaction properties at low compression pressure, of plasticized HPMC K4M (HPMC 2208) i.e. HPMC K4M plasticized using plasticizer like propylene glycol [6]. This was attributed to the plasticization effect of propylene glycol, which caused an improved deformation and internal bonding [6].

HPMC have been categorized into different grades like A, E, K, and F

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grades based on the methoxyl and hydropropoxyl substitution. Literature shows that K type of HPMC has better compressibility than E and F grade of HPMC [7]. However, even the Directly Compressible grade of K-type HPMC shows poor or very poor flow properties as well as low bulk density(~ 0.3 g/ml) [8]. Such a low bulk density may create risk of segregation, during storage or compression stage, if commonly used excipients with higher bulk density like Pregelatinized Starch, Dicalcium Phosphate or Lactose anhydrous or monohydrate are used in the formulation for direct compression process. Also, HPMC K100LV was found to have greater tendency to absorb almost 7% moisture at 60% relative humidity at 25 °C [9]; this makes the K type HPMC less suitable for use in direct compression application.

Recently, new grade of low T_g HPMC (Affinisol™) was developed by Dow Chemicals to cater the needs of formulation scientist for developing melt-extrusion-based formulations. Interestingly, due to the low glass transition temperature, Affinisol™ polymers might also show better compactability, since T_g can be reversibly exceeded at relatively lower compression forces, and if they show favorable powder physical properties like bulk/tapped density and flow properties, they can be used a binder/filler for immediate release products and hydrophilic direct compression matrix former for developing sustained release drug delivery systems. Therefore, the present study was undertaken to evaluate the compaction and physical properties of Affinisol™ HPMC polymers for potential use in tablet formulation. HPMC E15 was used for compaction studies for reference purposes since it had similar degree of methoxy substitution and similar viscosity as Affinisol™ HPMC 15 LV. Starch 1500 was used in the lubricant sensitivity study since it has a plastic fracture and exhibits lubricant sensitivity. We believe that this study will help to understand the compaction and flow properties of Affinisol™ polymers and propose their use in future formulation development of direct compression based tablet dosage form.

2. Materials

Affinisol™ AFFINISOL HPMC HME 15LV and 100LV were received from Dow Chemicals (Midland, MI) and Affinisol™ AFFINISOL HPMC HME 4 M LV was received from Colorcon (Westpoint, PA) as samples. HPMC E15 was purchased from Dow Chemicals (Midland, MI). Starch 1500 was purchased from Colorcon (Westpoint, PA). Magnesium Stearate was purchased from Undesa (Genova, Italy).

3. Methods

3.1. Differential Scanning Calorimetry (DSC) studies

Differential scanning calorimetry for the polymers was carried out to determine their glass transition temperatures. DSC analysis was performed using Q200 ™ DSC differential scanning calorimeter (TA Instrument, New Castle, DE). Weighed samples (5–10 mg) were placed in T_{zero} aluminum pans and crimped with a T_{zero} lid. DSC thermograms were obtained at the heating rate of 3 °C/min from 30 to 150 °C comparing with the similar blank pan as a reference and continuous nitrogen flow was maintained to obtain inert atmospheres. Indium was used as a reference standard and Universal analysis software (TA Instrument, New Castle, DE) was used for the data analysis.

3.2. Powder physical properties

3.2.1. Bulk/tapped density

Samples between 80 and 90 cc were poured in graduated glass cylinder, using a funnel, without disturbing the bed. The uneven powder bed was leveled carefully using a stainless steel spatula. This initial volume was recorded as bulk volume (V_b) and the bulk density (ρ_B) was calculated as per Equation (1). The cylinders were tapped in increments of 250 taps using a Vankel Tapped Density tester. The test was discontinued when the bed volume remained unchanged from the previous reading. The final volume was recorded as Tapped Volume (V_T). The Tapped density (ρ_T) was calculated using Equation (2).

$$\rho_B = \frac{W}{V_B} \quad (1)$$

$$\rho_T = \frac{W}{V_T} \quad (2)$$

3.2.2. Powder flow

3.2.2.1. Angle of repose. Powder was passed at 45° angle from a funnel until the tip of the heap of powder reaches the bottom tip of the funnel. The circumference (C) and the height of the heap (h) were noted and the angle of repose was calculated as per Equation (3).

$$\text{Angle of Repose} = \tan^{-1}\left(\frac{2\pi h}{C}\right) \quad (3)$$

3.2.2.2. Compressibility index and Hausner's ratio. Compressibility index or Carr's index and Hausner's ratio are simple fast and popular method of predicting flow characteristics. Carr's index and Hausner's ratio can be determined using Equation (4) and Equation (5), respectively [10]. Carr's index and Hausner's ratio were calculated using the bulk and tapped density results.

$$\text{Carr's Index} = \left(\frac{V_B - V_T}{V_B}\right) \times 100 \quad (4)$$

$$\text{Hausner's ratio} = \left(\frac{\rho_T}{\rho_B}\right) \quad (5)$$

3.2.3. Loss on drying (unbound moisture content)

Unbound moisture can cause drug degradation for water sensitive drugs; therefore, excipients with low unbound moisture content are preferred for direct compression. Unbound moisture content was determined using moisture analyzer. Samples of approximately 2 g were taken for analysis. The test temperature was kept at 105 °C. The final moisture content was determined using the prediction mode.

3.3. Compactibility analysis

Two approaches are available for compactibility analysis-"out-of-die" and "in-die" approach. For "out-of-die" approach, compact dimensions are measured after ejection, while for "in-die" approach, the dimensions are estimated using apparatus like instrumented tablet press or compaction simulator. Generally, "in-die" approach is used due to generation of faster results and relative ease of data collection. However, in this study, an "out-of-die" approach was chosen to perform compactability analysis since "out-of-die" results represent only plastic deformation and not elastic deformation. Literature shows that "in-die" heckel plot analysis fails to accurately describe the compaction properties of pharmaceutical powders [11]. Powder were compressed into tablets of around 350 mg using a Hydraulic Carver Press (Carver, Menomonee Falls, WI) with oval flat punches at different compression force of 0.45, 0.6, 1, 1.2, 1.4, 1.6 and 2 metric ton. Compression pressure which is the compression force per unit area was derived using the compression force and die surface area. The tablets were immediately ejected as soon as the desired compression pressure was achieved while increasing the pressure. Compact volume was calculated using punch design software-TabletCAD® from Natoli (Saint Charles, MO). Compact dimensions (diameter and thickness) in mm were measured with a digital thickness gauge (Mitutoya, IL) up to two decimal places. Data fitting was performed employing the Microsoft® Excel.

3.3.1. Axial expansion of the compact post-compression

Post-compression axial expansion provides information on the

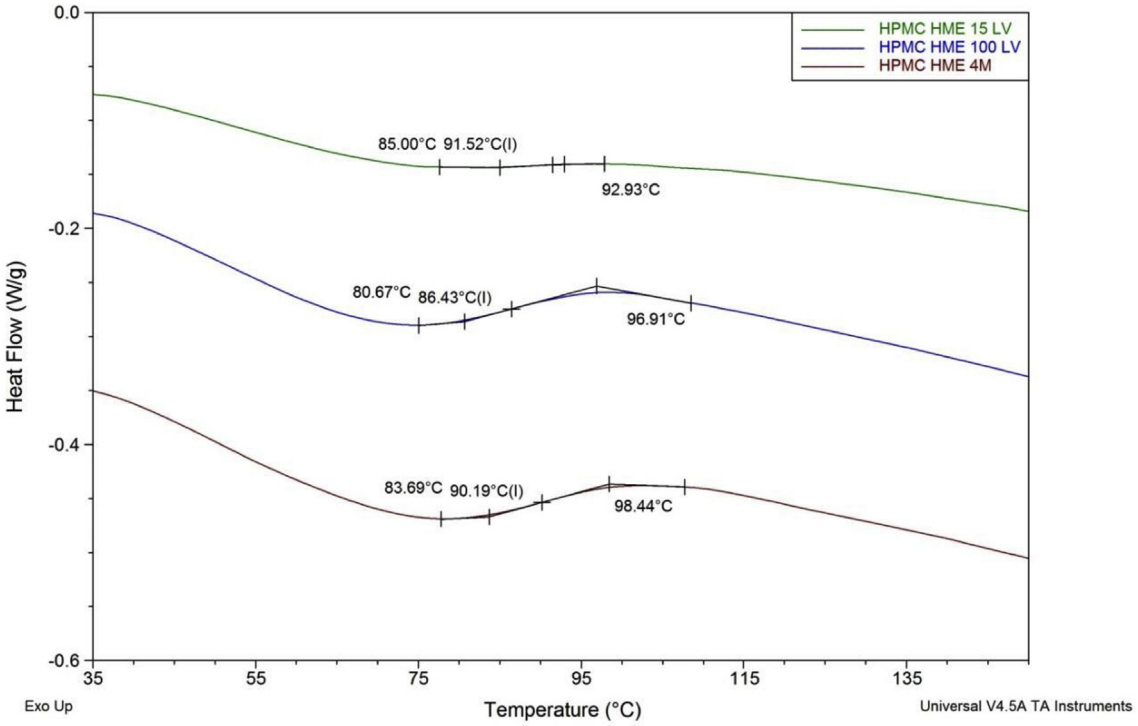

Fig. 1. DSC thermogram of Affinisol HPMC polymers at heating rate of 3 °C/min.

tendency of the tablet to cap or laminate on storage. Axial expansion occurs due to the need of the excipients for elastic recovery after compaction. Axial expansion causes the internal bonds to break while the tablet expands axially. Stronger inter-particle bonds prevent axial expansion post-compression. The Axial expansion was calculated from tablet thickness measured 24 h post-compression with a digital micrometer, using Equation (6):

$$\textbf{Axial Expansion}(\%) = \left(\frac{\mathbf{t} - \mathbf{t_c}}{\mathbf{t_c}}\right) \times 100 \tag{6}$$

where t is the axial thickness after 24 h compression and t_c is the initial axial thickness of the tablet measured after 1 min after compaction.

3.3.2. Analysis using heckel model

The equation for Heckel model for powder compressibility is given by Equation (7),

$$\mathbf{Ln}\left(\frac{1}{\varepsilon}\right) = \mathbf{kP} + \mathbf{A},\ \ \mathbf{D} = \frac{\rho_a}{\rho_t},\ \ \varepsilon = 1 - \mathbf{D} \tag{7}$$

where *D* is the relative compact density (solid fraction) at compression pressure *P*, ρ_a is the compact density, ρ_t is the true density of the material, ε is the porosity of the compact and *A* the intercept. This equation represents compact formation by die-filling, particle rearrangement, and deformation and bonding of discrete particles. The slope of the linear portion of the plot(k) is inversely related to the yield pressure (P_y) or yield stress. Yield pressure indicates the plasticity of the compressed material [12].

3.3.3. Analysis using Kawakita equation

The Kawakita equation describes the relationship between the degree of volume reduction of the powder and the applied pressure [13]. The Kawakita equation is described by Equation (8).

$$\frac{\mathbf{P}}{\mathbf{C}} = \frac{\mathbf{P}}{\mathbf{a}} + \frac{1}{\mathbf{ab}},\ \ \mathbf{C} = 1 - \frac{\rho_b}{\rho_a} \tag{8}$$

where ρ_a, ρ_b, *C*, and *P* are the compact apparent density, powder bulk density, degree of volume reduction and compression pressure, respectively. The constant "*a*" and "b" represent compressibility index and resistant forces to compression, respectively [14].

3.4. Hardness study

Powder was compressed as shown in section 3.3 and tested for the hardness using a Sotax Tablet Hardness tester (Westborough, MA).

3.5. Friability study

Powder were compressed into tablets of around 400 mg using a Hydraulic Carver Press with round concave punches at compression force of 0.6 metric ton. The tablets were immediately ejected as soon as the desired compression pressure was achieved. Tablets (6.5 g or more) were subjected to friability test as per USP specifications.

3.6. Lubricant sensitivity

In order to compare lubricant sensitivity, Affinisol™ HPMC polymers were compared to Starch 1500- direct-compression filler with plastic fracture. Affinisol™ HPMC polymers and Starch 1500 were individually mixed with magnesium stearate (1% w/w) in a cylindrical glass vial with a cap, in a tangential circular motion at 25 rpm for 15 min. Compacts of around 0.400 g were made at 1 metric ton compression force using concave punches with a Hydraulic Carver Press (Carver, Menomonee Falls, WI). Lubricant sensitivity was expressed as a ratio according to the following relationship (Equation (9)):

$$\textbf{Lubricant Sensitivity} = \left(\frac{\mathbf{H_0} - \mathbf{H_l}}{\mathbf{H_0}}\right)\mathbf{x}100 \tag{9}$$

Where H_0 and H_l are the hardness of tablets prepared without and with lubricant, respectively. This test was performed on a Sotax Tablet Hardness tester (Westborough, MA).

Table 1
Substitution and glass transition temperatures of different types of HPMC.

Product Name	Ethoxyl,%[a]	Methoxyl,%[a]	Hydroxypropoxyl[a], %	Total Substitiution, %	Methoxy/Hydroxypropoxy ratio	Glass transition temperature (°C)
Cellulose	–	–	–	0	–	220 [21]
Ethylcellulose	48–49.5	–	–	48–49.5	–	133[Unpublished research]
Methocel A type (Methylcelluose)	–	27.5–31.5	–	27.5–31.5	–	196 for MC A4M [22]
Methocel Ktype	–	19.0–24.0	7.0–12.0	26.0–36.0	2.26	196 °C(HPMC K4M) [16]
METHOCEL F type	–	27.0–30.0	4.0–7.5	31.0–37.5	4.95	173 °C(HPMC F4M) [16]
METHOCEL E type	–	28.0–30.0	7.0–12.0	35.0–42.0	3.05	163 °C(HPMC E4M) [16]
Affinisol™	–	22.0–27.0	25.0–32.0	47.0–59.0	0.89	90 °C for AFFINISOL HPMC HME 4 M

[a] Dow Chemical Co. limits.

Table 2
Powder properties of Affinisol™ HPMC polymers.

Parameter	AFFINISOL HPMC HME 15 LV	AFFINISOL HPMC HME100 LV	AFFINISOL HPMC HME 4 M	HPMC E15
Bulk Density(g/cc) (n = 2)	0.466	0.427	0.432	0.351
Tapped Density(g/cc) (n = 2)	0.575	0.527	0.533	0.548
Angle of Repose (°) (n = 2)	31	31	33	41
Loss on Drying (%)	1.73	2.21	1.89	2.10
Carr's Index	19	19	19	36
Hausner's ratio	1.23	1.23	1.23	1.56

Table 3
Heckel plot parameters for different grades of HPMC.

Polymer	Slope 'k' (MPa^{-1})	Intercept	Yield Pressure (P_y) (MPa)	Regression coefficient of line segment used for analysis (r^2)
AFFINISOL HPMC HME 15 LV[a]	0.007078	1.00	141	1.00
AFFINISOL HPMC HME 100 LV[a]	0.006457	1.04	155	0.99
AFFINISOL HPMC HME 4 M[a]	0.006643	1.00	151	0.99
HPMC E15[b]	0.004956	0.98	190	0.98

[a] Values of slope and intercept were obtained using the linearity of the compression pressures up to 110 MPa.
[b] Values of slope and intercept were obtained using the linearity of the compression pressures up to 133 MPa.

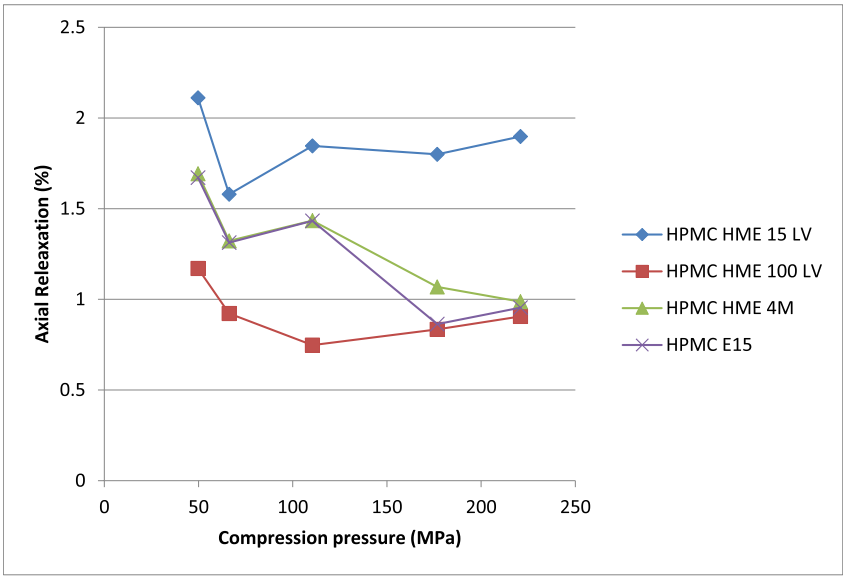

Fig. 2. Axial relaxation of Affinisol™ HPMC and HPMC E15 compacts as a function of compression pressure at 24 h after compression. Mean values (n = 3).

4. Results and discussion

4.1. Differential Scanning Calorimetry (DSC) studies

The DSC thermogram (Fig. 1) shows the T_g of Affinisol™ HPMC polymers was around 90 °C which is much lower than that of HPMC E15 (170–180 °C) [15]. Literature shows that increase in substitution and methoxyl/hydroxpropoxyl ratio shows lower T_g [16]. However, data presented in Table 1 shows that increase in substitution of cellulose leads to polymers with lower T_g. A strong correlation was observed between the degree of total substitution and T_g. Therefore, the decrease in T_g of Affinisol™ Polymers can be attributed to the increase in total

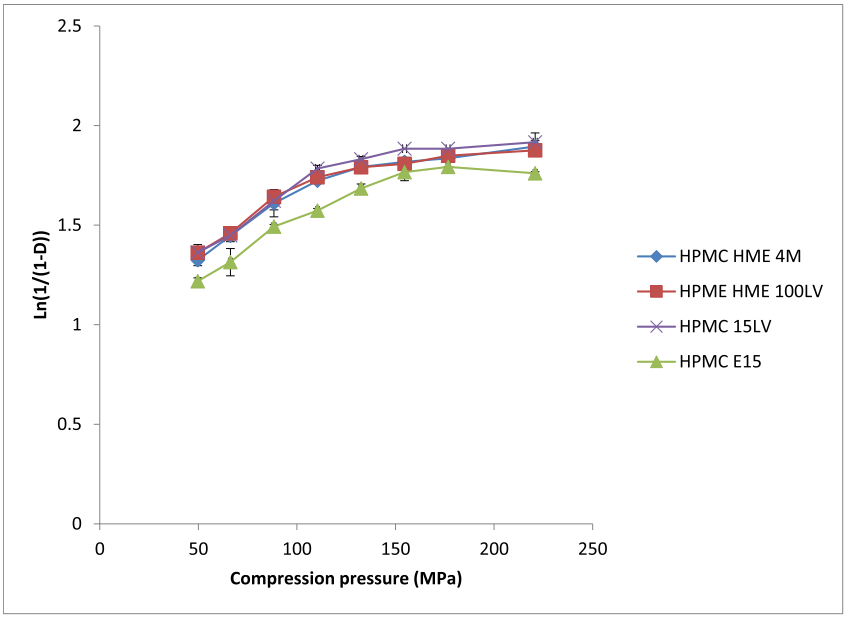

Fig. 3. Heckel Plot for Affinisol™ HPMC and HPMC E15. Mean values (n = 3) ± S.D.

Table 4
Kawakita equation parameters for different grades of HPMC.

Polymer	a	1/b	Regression coefficient (r^2)
AFFINISOL HPMC HME15 LV	63.7	8.93	1.00
AFFINISOL HPMC HME 100 LV	66.9	6.81	1.00
AFFINISOL HPMC HME 4 M	66.6	7.97	1.00
HPMC E15	76.4	6.42	1.00

substitution. The total substitution of Affinisol™ Polymers is 47.0–59.0% yielding a T_g of around 90 °C; this can be correlated to the case of ethylcellulose with total substitution of 48–49.5% and T_g of around 133 °C [Unpublished data]. Increase in substitution decreased the glass transition temperature due to reduction in the intermolecular hydrogen bonding and hence crystallinity of polymer, which resulted in glass transition at a lower temperature.

4.2. Powder physical properties

Binder/filler should have acceptable flow property and moisture content for a successful tablet formulation. Flow property of binder/filler is critical during the tablet compression, while moisture content is critical for drug stability. Table 2 shows the powder physical properties of Affinisol™ HPMC polymers and HPMC E15. The measured Carr's index of 19 and Hausner's ratio of 1.23 indicates that the powder flow was fair. However, angle of repose of 31°–33° indicates the good flow. On the other hand, HPMC E15 shows very poor flow. Overall, Affinisol™ HPMC 15 LV showed acceptable flow property to be used as direct compression binder/filler. Binder/filler should have low moisture content, which helps in minimizing drug degradation due hydrolysis. The % loss on drying of less than 2.5% indicates that the powder did not have excessive moisture, which can be deleterious to a drug that is sensitive to hydrolysis. Literature shows Affinisol™ HPMC polymers to absorb around 3% of moisture compared to 7% moisture at 60% relative humidity at 25 °C [9] (Table 3).

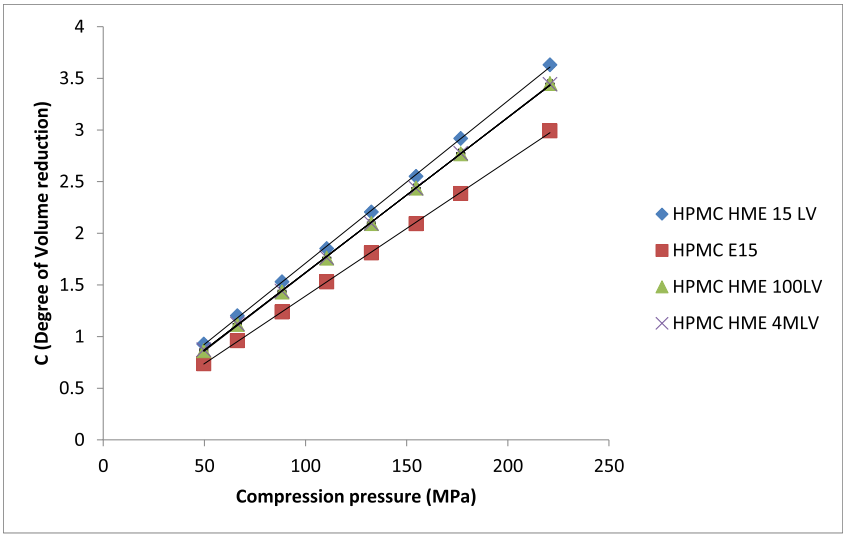

Fig. 4. Kawakita plot for Affinisol™ HPMC polymers and HPMC E15. Mean values (n = 3) ± S.D.

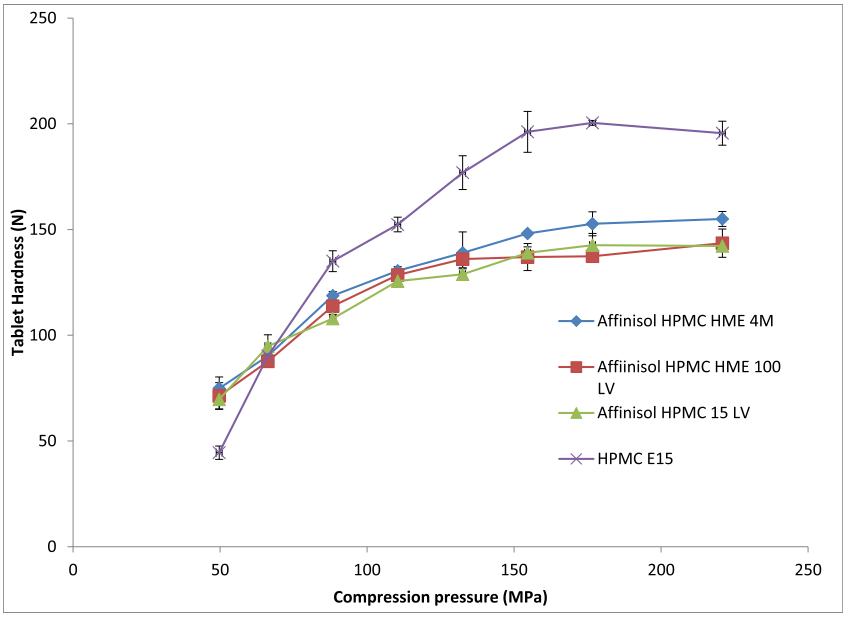

Fig. 5. Effect of compression pressure on hardness of tablets prepared using Affinisol™ HPMC and HPMC E15. Mean values (n = 3) ± S.D.

Table 5
Friability of HPMC 15LV and HPMC E15 tablets at 0.6 metric ton compression pressure.

Polymer	Friability (%)
AFFINISOL HPMC HME 15 LV	0.3
AFFINISOL HPMC HME100 LV	0.6
AFFINISOL HPMC HME 4 M	0.1
HPMC E15	2.7

4.3. Compactibility analysis

4.3.1. Axial expansion of the compact post-compression

Fig. 2 shows axial relaxation of Affinisol™ HPMC polymers and HPMC E15. It can be observed that the axial relaxation is maximum at low pressure. This is due to the low porosity density at lower compression pressure that causes lesser number of inter-particle bonds. At higher compression (more than 50 MPa), the axial expansion did not change significantly ($p > 0.05$). Overall, the axial expansion at any pressure was less than 2.5% in 24 h. Such a low axial expansion might be due to the plastic nature of the polymer and formation of inter-particle bonds, due to the presence of hydroxyl group, during compaction (Fig. 3).

4.3.2. Analysis using heckel model

Heckel plot analysis shows that Affinisol™ HPMC has lower yield pressure compared to HPMC E15. This can be attributed to the lower glass transition temperature of the Affinisol™ HPMC, which leads to deformation at lower compression pressure. It should be stressed that the compaction here is solely due to plastic deformation since the tablets were allowed for elastic recovery before the measurement of the dimensions of the compacts were taken.

4.3.3. Analysis using Kawakita equation

It can be observed that Affinisol™ polymers showed higher compressibility index "a" than HPMC E15. This is possible due to lower T_g of Affinisol™ polymers, which is reversibly exceeded during compression at lower compression pressures. Table 4 shows that the values of parameter "a", which is the maximum degree of volume reduction, is more for HPMC E15 than Affinisol™ HPMC polymers. This can be attributed to lower bulk density and the ability to form more inter-particle bonding due to inter molecular hydrogen bonding in HPMC E15 than in Affinisol™ HPMC polymers. This results in higher degree of volume reduction for HPMC E15 than Affinisol™ HPMC polymers. Parameter "1/b" represents cohesiveness or plasticity. Higher values of "1/b" represent more plasticity or lesser resistance to compression. It can be observed that compared to Affinisol™ HPMC polymers, HPMC E15 showed more resistance to compression due to lower plasticity. This can be attributed to the lower T_g of the former than the latter

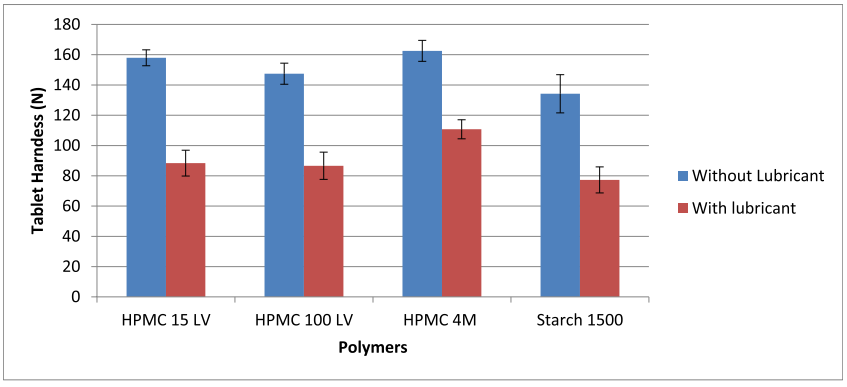

Fig. 6. Effect of Lubricant (magnesium stearate) on tablet hardness of different polymers. Mean values (n = 10).

(Fig. 4).

4.4. Hardness study

Fig. 5 shows the hardness of tablets compressed at lower compression pressures (less than 88 MPa) produced stronger tablet of Affinisol™ HPMC 15LV compared to HPMC E15. However, with the increase in compression pressure, the increase in hardness of Affinisol™ HPMC 15LV tablets reached a plateau. This can be attributed to achieving a limiting porosity and maximum densification at pressure of 88 MPa, above which, there was no further formation of bonds. HPMC E15 tablets showed a steeper increase in hardness between 66 MPa and 110 MPa metric ton of compression pressure. This may be due to the lower degree of substitution allowing more hydroxyl groups to form hydrogen bonds. Similar trend was observed for Methocel F4M and K4M compared to E4M polymer, which showed increase in strength of tablet with increase in compression pressure [7]. Stronger tablets of HPMC E15 compared to Affinisol™ HPMC polymers at compression pressure at 88 MPa and higher can be attributed higher proportion of aromatic hydroxyl group that help in establishing inter-particle bonding once the inter-particle distance is sufficiently reduced to form during compression. Interestingly, increase in hydroxypropoxyl substitution in also introduces an aliphatic hydroxyl group capable of forming hydrogen bonds; however, aromatic hydroxyl groups tend to form stronger hydrogen bonding interaction than the aliphatic hydroxyl group due to the ability of aromatic hydroxyl group to distribute the accepted electron cloud over the aromatic ring.

Higher hardness of Affinisol™ HPMC polymers, at lower compression pressures, might be attributed to the low glass transition temperature of Affinisol™ HPMC 15 LV, which is reversible exceeded at low compaction pressure and thereby causing greater inter-particle bonding resulting in stronger tablets. Similar observations were made for plasticized Affinisol™ HPMC K4M compared to unplasticized Affinisol™ HPMC K4M, where the tensile strength was higher with plasticized HPMC K4M at lower compression pressure compared to unplasticized Affinisol™ HPMC K4M [6]. Also, the tensile strength of plasticized HPMC K4M tablets was found to reach a plateau at higher hardness [6]. Also, literature shows that HPC SSL as a binder led to tablets with higher tensile strength compared to Kollidon® VA64 Fine (copovidone) at lower compression pressure [17]. It can be attributed to the lower glass transition temperature of $-25 \sim 0\,^{\circ}C$ for HPC(18) compared to 101 °C of Kollidon VA 64 [19].

4.5. Friability study

Table 5 shows at even at 0.6 metric ton compression force, the tablets of Affinisol™ polymers met the friability specifications. On the other hand, HPMC E15 yields highly friable tablets. Due to lower T_g of HPMC 15 LV, during compression, the T_g is reversibly exceeded at lower temperature, yielding stronger tablets at lower compression pressure. Similarly, tablets prepared with HPC SSL showed lower friability compared to those prepared with Kollidon Va 64 F [17]. It could also be attributed to the lower glass transition temperature of $-25 \sim 0\,^{\circ}C$ for HPC [18] compared to 101 °C of Kollidon VA 64 [19]. This observation shows that Affinisol™ polymers have superior compression properties and can yield tablets with stronger edges, at lower compression pressures.

4.6. Lubricant sensitivity

Fig. 6 shows that Affinisol™ polymers are sensitive to lubricant. The lubricant sensitivity of Affinisol™ HPMC 15 LV, Affinisol™ HPMC 100 LV, Affinisol™ HPMC 4 M and Starch 1500 were calculated to be 0.44, 0.41, 0.32 and 0.42, respectively. This indicates that more than 30% of compressibility was lost due to lubrication. This was attributed to the plastic nature of the Affinisol™ HPMC polymers. Plastic materials like Affinisol™ HPMC polymers deform under pressure but did not fracture to create new surface devoid of lubricant [20]. This led to reduced surface area for bonding and therefore tablet hardness decreases during lubrication.

5. Conclusion

This work has examined the potential for low T_g HPMC grade to be used as a filler/binder. Compared to higher T_g HPMC, Affinisol™ HPMC polymers yield stronger and less friable tablets at lower compression pressure. This study confirms that lowering the glass transition temperature of HPMC results in superior compaction properties at lower compression pressures. Also, Affinisol™ HPMC possesses acceptable powder flow properties, which make them suitable candidate for use as binder or controlled release matrix former in direct compression applications.

Conflicts of interest

None.

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