Krka d.d. Novo mesto[1], Faculty of Pharmacy[2], University of Ljubljana, Ljubljana, Slovenia

The effect of cores and coating dispersion composition on the mechanical and adhesion properties of hydroxypropyl methylcellulose films

M. Banovec[1], O. Planinšek[2], F. Vrečer[1,2]

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Martin Banovec, KRKA d.d. Novo mesto, Šmarješka cesta 6, 8000 Novo mesto, Slovenia
martinbanovec@gmail.com

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The influence of different additives on the mechanical properties of hydroxypropyl methylcellulose (HPMC) free films was studied using tensile testing. Free films were prepared using the cast method and sliced into bands, and their tensile strength and maximal elongation at break was measured. The results showed that the addition of PEG 400 and polysorbate 80 into the coating formulation had the most influence on the films' mechanical properties compared to the HPMC film used as a control. Tablet cores composed of microcrystalline cellulose and lactose with and without Mg stearate and compressed at three different compression forces were tested for wettability with coating formulations containing PEG 400 and polysorbate 80. For formulations with no Mg stearate added, the contact angle decreased with increasing core hardness and it also coincided with greater adhesion force of the coating. The addition of Mg stearate in the core led to reduced adhesion of the film coating with PEG 400, whereas the influence on the adhesion force of the film coating containing polysorbate 80 was negligible. The results also show that the adhesion force, regardless of the tablet core formulation, is highest at medium core hardness.

1. Introduction

Film coating is a highly sophisticated process that is generally defined as the application of a thin polymeric film onto the surface of solid cores such as tablets, pellets, granules, or crystals. Film coatings are used for improving tablet appearance, masking unpleasant taste and odor, distinguishing products with different strengths, easing ingestion, improving product stability, and drug release regulation in the body. Tablet coatings can also allow higher packaging speeds by reducing both the friction and dust generation of tablets (Canyadi et al. 2011).

One of the most important requirements of a film coating, regardless of its purpose, is good adhesion to the substrate and lack of any defect on the surface of the coated tablets. After applying coating dispersion to the tablet cores, two forces immediately develop; one operates between the film-forming polymer molecules (cohesion force or internal stresses) and the other between the film and the substrate (adhesion force) (Saringat et al. 2005). In the past, several methods have been used to predict or determine adhesion, which have also been described in our previous research (Banovec et al. 2013).

The adhesion of the coating to the tablet depends on a set of interacting factors related to the coating formulation, the tablet core, and processing conditions. Among the process-related factors, processing equipment and spraying conditions are definitely most important. Canyadi et al. (2011) used a Supercell coating system in which tablets are air-fluidized in a chamber in their study. With the aid of a statistical design of experiments (DoE) they quantified the effects of various coating process conditions and their interactions on the quality of film-coated tablets. Khan and Fell (2005) studied the influence of coating process parameters on film tablet adhesion. In their study, they established that atomizing air pressure and inlet air temperature have the biggest influence on adhesion.

Among coating-related factors, the composition greatly influences adhesion and film properties. Fung and Parrot (1980) studied the influence of two vehicles on film–tablet adhesion. They established that the force of adhesion is significantly greater whenever an organic solvent–based film is analyzed instead of an aqueous-based one. In another study, the frequently used polymer HPMC was examined after adding it in water or ethanol dispersion (Bajdik et al. 2005). Significant differences were found in the breaking force of free films which was attributed by the variation in the inner film structure. It was also found that the use of ethanol enhanced the processability due to easier atomization and the shorter drying period. Nowadays, primarily due to environmental concerns, mostly aqueous-based systems are preferred for coatings (Obara and McGinity 1994).

Another very important component of a film coating is the plasticizer. Its influence was already studied in the 1970 s (Fisher and Rowe 1976). It was established that the plasticizer can change the mechanical and adhesive properties of the film coating with incorporation between polymer chains.

Pigments, primarily represented by aluminum lakes of water-soluble dyes, opacifiers, and various inorganic materials, can also influence the adhesive properties of the polymer. Contradictory information on the influence of TiO_2 as the basic pigment used in a film coating can be found in the literature. Some authors reported on the increased adhesion of HPMC films with the addition of TiO_2, (Lehtola et al. 1995; Felton and McGinity 1999), whereas other found a decrease of adhesion force in the presence of TiO_2 (Fisher and Rowe 1976). Talc, which is usually added into the coating as an anti-tacking agent, reduces the adhesion force between the polymer and the core (Okhafame and York

1985a). The viscosity and surface tension of coating dispersions also play an important role and influence their adhesive properties. It influences the degree and extent of coating dispersion penetration into the tablet surface and thus the adhesion force (McGinity 1997; Hossain and Ayers 1990; Lippold et al. 1990). The role and influence of surface tension was studied by Wulf et al. (2000). They stressed the importance of controlling this and found, among other things, that overly high surface tension reduces the wettability of the core, whereas a value that is too low hinders film formation, which is usually reflected as orange peel patterning on the tablet surface.

Among substrate-related factors, the most important are core porosity, roughness, wettability, hardness, hydrophobicity of the tablet surface, and core composition (Missaghi and Fassihi 2004). Roughness of the core surface correlates with the compaction force used for tablet compression. Fisher and Rowe (1976) proposed that higher compression force results in a lower adhesion force of the coating due to lower roughness of the core's surface and, with it, lesser contact surface area. Because adhesion is the result of intermolecular bonds between the coating and the substrate, the ingredients of the core itself also affect the joint strength. It was established that the presence of microcrystalline cellulose (MCC) in a core, due to the free OH groups, enables the formation of an additional number of H-bonds with HPMC as the most commonly used polymer in film coatings that results in greater adhesion (Lehtola et al. 1995). The addition of stearic acid to the core has a similar effect due to a free polar carboxyl group. If this group is combined with glycerol to form glyceryl esters present in hydrogenated stearin oil, polymer adhesion decreases (Rowe 1977).

In our research, a special custom-designed tablet holder was developed and adhesion force was measured and evaluated with the aid of a texture analyzer. The objectives of this study are:

1) To study the effect of individual coating components on mechanical properties (film tensile strength, elongation at film break) of HPMC free films.

2) To study the influence of the commonly used lubricant magnesium stearate in tablet core formulation and the core's hardness on film-tablet adhesion.

3) To investigate the influence of the composition of HPMC-based coating dispersion in the presence of selected plasticizers or surfactants on the adhesion of the coating onto the cores.

2. Investigations, results and discussions

The most commonly determined mechanical properties of polymeric free films are tensile strength and elongation at break (Saringat et al. 2005). These are measured to assess the strength or toughness of the film and its deformation characteristics.

2.1. Elongation at break

Flexibility is the ability of a coating to be bent or flexed in forming operations without cracking, losing adhesion, or failing in some other manner (Koleske 2006). It refers to the maximum extension gained by the film at break and is required so that coatings can conform to dimensional changes of the substrate. With low-flexibility coatings, film cracking may occur. This is especially important when a tablet core contains a highly hygroscopic matter, such as a superdisintegrant (Thibert and Hancock 1995). In the presence of moisture, absorption of water occurs, resulting in tablet swelling.

Elongations at film fracture were measured for all 16 casted films presented in Table 2. Figure 1 depicts the percent of extensions where film fracture had occurred. The results show that some excipients increase and other decrease pure HPMC elasticity.

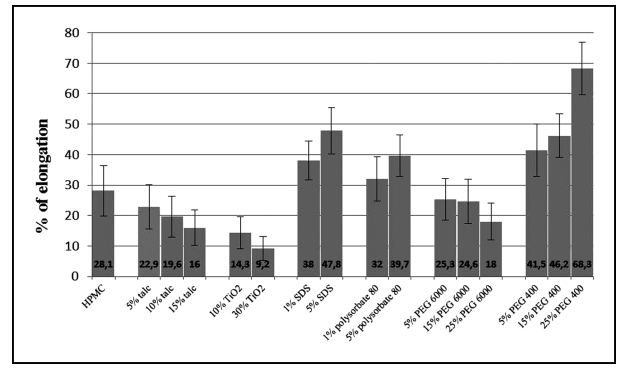


Fig. 1: Elongation at break expressed in % of initial free film length for formulations F1–F16.

It is also evident that the film containing 25% of PEG 400 as a plasticizer has the highest elasticity (elongation). It is known that plasticizers' molecules intercalate among polymer chains and change the modulus of elasticity, which makes the polymer more extendable and flexible (Gutierrez-Rocca and McGinity 1993). It is interesting, however, that the addition of PEG 6000 has a negative influence on the film's elasticity. The different effect of both PEGs could be explained by the gel theory (Honary and Orafai 2002). According to this theory, active center forces attract polymer molecules to each other in solution. The formation and breakage of these bonds are in a dynamic equilibrium in solution. As they break, water molecules compete for the active sites. Plasticizers, if present in the solution, are also in competition for the same sites and will thus reduce the number of polymer centers and the number of polymer-polymer contacts, so they could decrease the rigidity of the three-dimensional structure formed on drying and change the mechanical properties of the film. Better softening of low-molecular-weight PEG in comparison to high-molecular-weight PEG is a consequence of the fact that there will be more molecules and therefore presumably more chances of competition for active sites per weight of added PEG (Porter 1980).

SDS and polysorbate 80 also have a positive influence on film elongation. Better flexibility is attributed to lower surface tension of the corresponding polymer dispersion. Reduced elongation was observed when talc or TiO_2 was added to the formulation, which is in line with the results found in the literature (Okhafame and York 1984, 1985b). Both substances are insoluble and do not interact with polymer. They are normally added to improve the aesthetic appearance of the film, but have a rather negative effect on its mechanical properties such as extensibility (Porter 1980).

2.2. Tensile strength at break

An ideal film should be hard, tough, and extendible, and characterized by high tensile strength, a high elastic modulus, and moderate elongation (Remunan-Lopez and Bodmeier 1996). Figure 2 shows maximal tensile strengths for all coatings. It is evident that the tensile strength of plasticized HPMC films (F11–F16) is lower in comparison to the control (F1). Because polymers used in coating dispersions are relatively brittle in nature, the addition of plasticizer makes them more pliable and less sensitive to mechanical stresses. This effect linearly increases as the concentration of plasticizer increases. Such results are in line with the results of previous research (Har Kwok et al. 2004). The decrease in the tensile strength of plasticized HPMC films is attributed to increased chain mobility of HPMC. Plasticizer interacts with HPMC, and this interreaction involves hydrogen bonding between adjacent segments

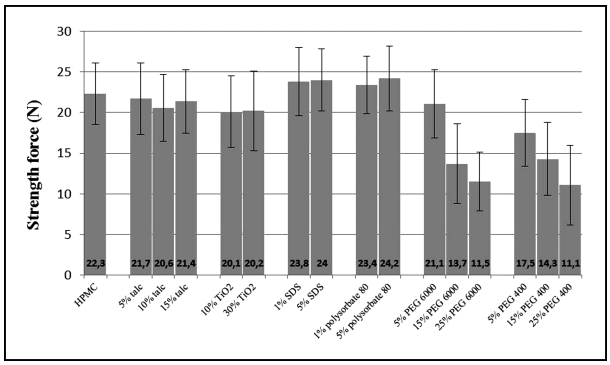


Fig. 2: Tensile strengths at film break for formulations F1–F16.

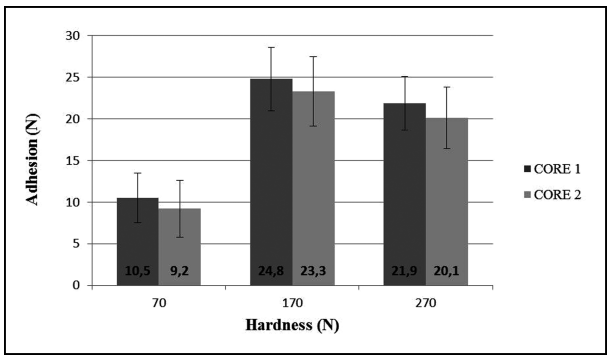


Fig. 3: Relationship between adhesion force and two tablet formulations compressed at three different forces coated with formulation F10.

of HPMC films, in which plasticizer becomes sandwiched. The result is a loose structure in which reduced bonds between the segments of HPMC film leads to enhanced segmental mobility characterized by a decrease in the film tensile strength and increase in its elongation.

The addition of insoluble talc and TiO_2 pigment does not change the tensile strength of casted films significantly. It means that HPMC films became slightly more brittle as the concentration of insoluble talc and TiO_2 increases. In contrast, the tensile strength of casted films is slightly increased with the addition of both surfactants. This could be related to improved polymer chain mobility due to polymer-surfactant interactions, which results in lower internal stresses within cellulosic film. The maximum strength force was observed with 5% polysorbate 80 in the film. Based on the mechanical and adhesive properties of free films, two coating formulations were chosen for further adhesion investigations: formulation F10, containing 5% polysorbate 80 with the highest tensile strength and the best adhesive properties (Banovec et al. 2013), and formulation F16, containing 25% PEG 400 with the highest elongation at break. Subsequently we

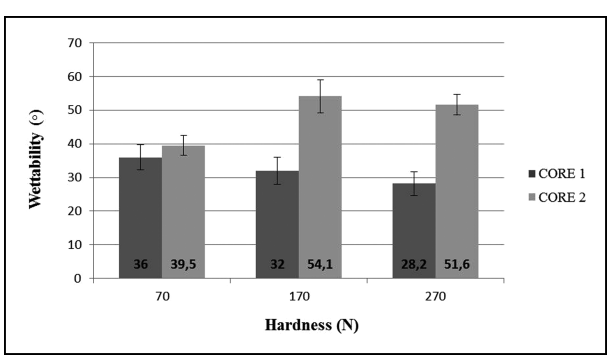


Fig. 4: Relationship between wettability and two tablet formulations compressed at three different forces coated with formulation F10.

studied the effect of different hardness levels and the presence of magnesium stearate (Mg stearate) in the cores on adhesion with the film coating. Mg stearate is a hydrophobic compound that normally acts as a lubricant to prevent tablet contents from sticking to the punches of the tableting machine. Aside from its lubricating role, the addition of Mg stearate in the core can alter the chemical properties of the tablet surface and thus influence polymer adhesion (Lehtola et al. 1995).

2.3. Influence of tablet hardness and presence of Mg stearate in the core on adhesion with coating formulation F10

Tablet hardness is an important parameter that, in addition to ensuring mechanical resistance, can also influence the film coating adhesion on the cores. Figure 3 depicts the influence of tablet hardness on the adhesion force of the film coating.

This force increases at medium hardness and slightly decreases again at the highest tablet hardness. Fisher and Rowe (1976) had already come to similar conclusions finding that above the critical compression force the measured adhesion decreased as the compression pressure increased. Unlike the hardness, the addition of Mg stearate in the core does not have a significant influence on adhesion force with a coating containing surfactant (F10). It is clear from the data in Figure 3 that the adhesion force slightly decreases compared to cores that do not contain Mg stearate. Strong adhesion of the film on both core formulations can be attributed to the amphiphilic properties of the surfactant in the coating that, due to the polar and non-polar part, reduce the surface tension of the coating liquid, enable good spreading of coating droplets onto tablet cores and thus helping form a greater number of H-bonds and through this better adhesion. To confirm these explanations, the wettability of the cores with coating dispersions was measured. Figure 4 depicts the influence of both the core formulation and tablet hardness on the contact angle of coating dispersion F10. In the case of cores with Mg stearate (CORE 2), the best wettability is observed at the lowest tablet hardness, whereas at both higher hardnesses the wettability significantly decreases. This is attributed to the reduction of porosity at higher core hardness and consequently lower penetration of the liquid into the tablet core. For the formulation without Mg stearate (CORE 1), however, the contact angle decreases with increasing hardness of the tablets, which can be attributed to decreased tablet surface roughness with increased tablet hardness. Better wettability of CORE 1 resulting from the absence of the hydrophobic stearate in the composition of the core is expected because Mg stearate is very hydrophobic.

According to the literature (Wood and Harder 1970) the contact angle between the coating formulation and substrate surface provides important information regarding substrate wettability. It would be expected that more wettable surfaces produce greater interactions and consequently lead to stronger adhesion. However, such relationships cannot be confirmed by comparing the data from Figures 3 and 4. It is evident that contact angles of coating formulations were all below 60° showing good wettability of the tablet cores. Although the values for both formulations were different, adhesion force of the coating of both types of cores is most probably influenced by some other factors besides wettability of the core.

2.4. Influence of tablet hardness and presence of Mg stearate in the core on the adhesion with coating formulation F16

Figure 5 depicts the adhesion force of coating formulation F16 (containing 25% PEG 400) with tablet cores by hardness. Similarly as with polysorbate 80 (F10), the adhesion force is

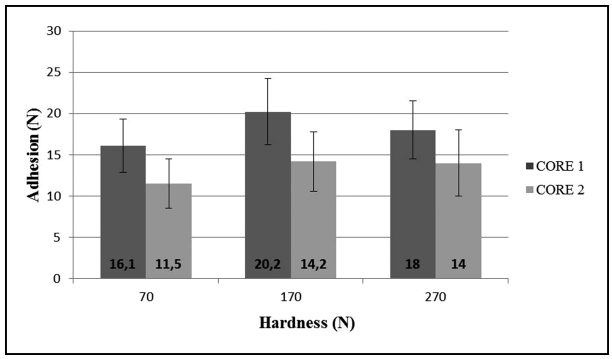


Fig. 5: Relationship between adhesion force and two tablet formulations compressed at three different forces coated with formulation F16.

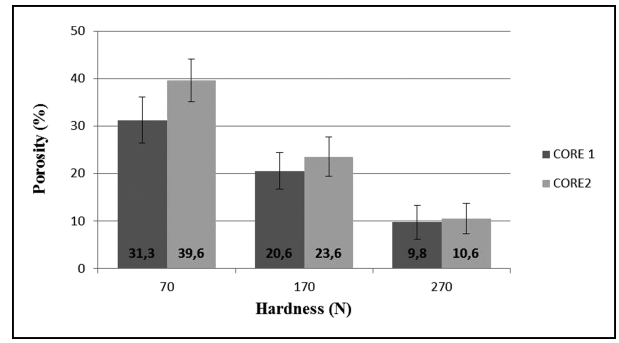


Fig. 7: Influence of hardness on tablet porosity (the numbers in columns mean average value of adhesion force).

the lowest with the lowest tablet hardness. An increase follows at medium hardness and decreases slightly at the highest tablet hardness. Despite a similar influence of core hardness on the film-tablet adhesion regardless of the coating formulations used, one can see a considerably greater effect of Mg stearate presence in the core on the adhesion force.

Comparing the adhesions of both core formulations at all three hardness levels, a significant drop in adhesion force is seen for cores that contain Mg stearate (CORE 2). Such results are in line with the assumption of Rowe who suggests that magnesium stearate interferes with the bond formation between the tablet surface and the coating polymer by presenting a surface consisting of non-polar hydrocarbon groups, and thus the measured adhesion is lowered (Rowe 1977).

The results in Fig. 6 show that influence of both core formulations and tablet hardness on wettability of coating formulation F16 is very similar to formulation F10. It is observed that for core formulations without Mg stearate (CORE 1) the contact angles decrease with tablet hardness. This is expected because rougher surfaces provide greater interfacial contact between the polymeric film and the tablet surface, resulting in stronger polymer adhesion. In addition, the cores without Mg stearate are less hydrophobic, leading to better wetting with aqueous-based coating dispersion.

In contrast, the contact angle increases with increasing tablet hardness for cores with Mg stearate (F2). A comparison of Figures 5 and 6 shows that for core formulations with Mg stearate (CORE 1) better wettability coincides with greater adhesion force, whereas for formulations without Mg stearate (CORE 2) there is an inverse relation because greater adhesion is observed for cores with lower wettability. Such a result is attributed to the difference in hydrophobicity due to the presence of Mg stearate in the core formulation (CORE 2).

The relation between tablet hardness and porosity is shown in Fig. 7. It indicates that tablet porosity decreases with an increase in core hardness.

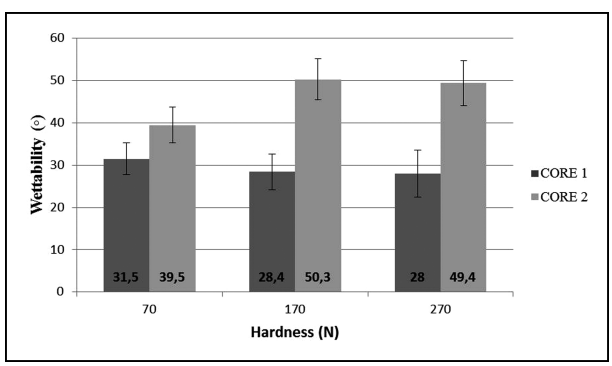


Fig. 6: Relationship between wettability and two tablet formulations compressed at three different forces coated with formulation F16.

This is expected because, at higher compression pressures, the particles of the compression mixture bind better between each other and therefore the compressed tablet roughness should also decrease. This also influences the contact area with which the film coating interacts. It is well known that roughening a substrate can exert a positive effect on joint strength by increasing the contact surface area and providing an interlocking mechanism for binding. In addition, this parameter could improve the spread of the coating dispersion by a capillary force mechanism (Orafai and Spring 2007). Theoretically, the rate and depth of polymer solution penetration could influence the interfacial contact between the polymer and the tablet, with a more porous tablet allowing faster penetration of the polymeric solution. The rank-order relationship between the tablet porosity and the adhesion force can be noticed in Figs. 3, 5, and 7. It was revealed that the maximum adhesion force was observed in the middle porosity tablets regardless to the tablet formulation. Moreover, as the lowest adhesion force was measured in the tablets with the highest porosity, our results are contradictory to the hypothesis suggested by Orafai and Spring (2007). Some conflicting results regarding the relationship between film adhesion, porosity, and hardness have already been published in previous literature (Fisher and Rowe 1976; Lehtola et al. 1995; Rowe 1978; Nadkarni et al. 1975).

Our study indicates that irrespective to formulation there could be a range of tablet porosity at which the adhesion force between the core and the film coating is the strongest. However, our results do not lead to the correct conclusion but rather to a speculation. To be able to quantify the optimal range, further investigations in this field should be performed.

2.5. Conclusion

The mechanical properties of free films (tensile strength, elongation at break) are highly affected by coating composition. It was found that the addition of plasticizer and surfactant influenced the mechanical properties the most compared to a control HPMC coating dispersion. Based on this, two different coating formulations containing polysorbate 80 or PEG 400 were selected and evaluated for their influence on tablet hardness and presence of Mg stearate in the core on the adhesion force. The results showed that the composition of the film coating, as well as the composition and mechanical properties (different

Table 1: Composition of tablet cores

Excipient	Core 1 (%)	Core 2 (%)
MCC	50.0	49.5
Tablettose 80	50.0	49.5
Mg stearate	0	1

Table 2: Composition of coating formulations

Formulation	% ratio of additive to HPMC	HPMC (w/w)	Quinol. yellow (w/w)	Talc (w/w)	TiO_2 (w/w)	SDS (w/w)	Polysorbate (w/w)	PEG 6000 (w/w)	PEG 400 (w/w)	Pur. water
F1	/	7.5	0.2	–	–	–	–	–	–	q. s.
F2	5% talc	7.5	0.2	0.375	–		–	–	–	q. s.
F3	10% talc	7.5	0.2	0.750	–		–	–	–	q. s.
F4	15% talc	7.5	0.2	1.125	–		–	–	–	q. s.
F5	10% TiO_2	7.5	0.2	–	0.750	–		–	–	q. s.
F6	30% TiO_2	7.5	0.2	–	2.250	–		–	–	q. s.
F7	1% SDS	7.5	0.2	–		0.075	–		–	q. s.
F8	5% SDS	7.5	0.2	–	–	0.375	–		–	q. s.
F9	1% polysorbate 80	7.5	0.2	–	–		0.075	–		q. s.
F10	5% polysorbate 80	7.5	0.2	–	–		0.375	–		q. s.
F11	5% PEG 6000	7.5	0.2		–	–		0.375	–	q. s.
F12	15% PEG 6000	7.5	0.2		–	–		1.125	–	q. s.
F13	25% PEG 6000	7.5	0.2		–	–	–	1.875	–	q. s.
F14	5% PEG 400	7.5	0.2	–		–	–		0.375	q. s.
F15	15% PEG 400	7.5	0.2	–		–	–	–	1.125	q. s.
F16	25% PEG 400	7.5	0.2	–		–	–	–	1.875	q. s.

tablet hardness levels) of the core, influence adhesion force. With the two coatings tested, it was proved that core hardness has a strong influence on adhesion force. Regardless of the core composition or film coating used, the greatest adhesion force was reached at middle core hardness. The addition of Mg stearate to the core significantly reduces adhesion force when using a coating dispersion that contains PEG 400 as a plasticizer of the coating polymer. However, the influence of Mg stearate on adhesion force is negligible for tablets coated with a coating dispersion containing polysorbate 80. For formulations without Mg stearate, the contact angle decreases with increasing core hardness and it also coincides with greater adhesion force. As expected, tablet porosity decreases for both compositions with increasing core hardness. The maximum adhesion force of coatings for both tablet formulations was observed at middle core porosity. In the future it will be advisable to include more polymers in the coating composition and investigate their influence on mechanical properties as well as on adhesion to cores containing active ingredients.

3. Experimental

3.1. Materials

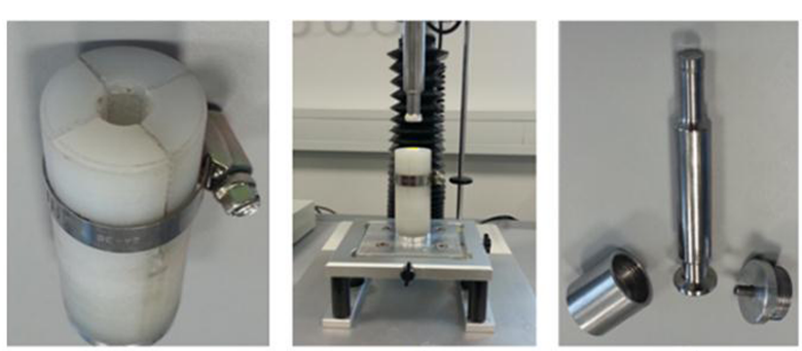
The materials used for preparing the tablet cores were MCC (Avicel PH102, FMC International, Wallingstown, Ireland), α-lactose monohydrate (Tablettose 80, Meggle GmbH, Wasserburg, Germany), and magnesium stearate (FACI SPA, Carasco, Italy). The coating formulations consisted of HPMC as a film-forming polymer (Pharmacoat 606, Shin-Etsu Chemical Co., Ltd., Tokyo, Japan), polyethylene glycol 400 (PEG 400, Merck KGaA, Darmstadt, Germany), polyethylene glycol 6000 (PEG 6000, Clariant Vertrieb GmbH & Co. KG, Frankfurt, Germany), talc (Imerys Talc Italia SpA, Porte, Italy), titanium dioxide (Tioxide Europe S.R.L., Scarlino, Italy), sodium dodecyl sulfate (SDS, Cognis Deutschland GmbH, Düsseldorf, Germany), polysorbate 80 (Tween, Croda Chocques SAS, Chocques, France), and quinoline yellow (Univar Explorer-Univar Limited, Bradford, UK).

3.2. Preparation of tablet cores

The composition of tablet cores that were prepared by direct compression is given in Table 1. All excipients were passed through a 40-mesh screen prior to tableting. The tablet cores were compressed on a rotary tableting machine (Fette 1200i, Schwarzenbek, Germany) using round punches (ϕ 12, R23) to three different hardness levels: 70N, 170N, and 270N. All tablet cores had a diameter of 9.1 mm, mass of 400 mg, and height of approximately 4.5 mm.

3.3. Preparation of casted films

The weighed amounts of polymer and colorant (quinoline yellow) were dispersed in 500 ml of purified water (in a 750 ml clean beaker) and the obtained dispersion (F1) was gently stirred for 1 h. Other ingredients were added to the prepared dispersion in required quantities according to Table 2. For coating formulations F2–F6, talc or titanium dioxide were previously separately homogenized with Ultra-Turrax® in a small amount of purified water. For formulations F7–F10 two surfactants (SDS or polysorbate 80) and for formulations F11–F16 two plasticizers (PEG 400 or PEG 6000) were added to the basic dispersion F1.
After homogenization, all free films were prepared using a cast method. The film coating dispersions were poured into a Petri dish plate and the solvent was allowed to evaporate at 50 °C within 2 hours in a drying chamber. The volume of the film coating dispersions used to prepare the film was quantified in such a manner that the resulting films had a thickness of approximately 80 to 90 μm. The dried films were cut with a knife and kept in a desiccator at ambient temperature and 30± 5% RH until analyzed.



A B C

Fig. 8: Setup of a texture analyzer for film-coating adhesion measurement: A) tablet holder, B) platform, C) upper holder.

3.4. Wettability of tablet cores

The contact angle measurements of coating dispersions on tablet cores were performed using the sessile drop method (Krüss Drop Shape Analysis, DSA 100). The tablets were lightly brushed to remove residual powder from the surface and placed on the stationary platen. One μL of the polymer dispersion, preheated to 40 °C (temperature used for tablet core coating), was dropped onto the tablet surface with a pipette and the contact angle was measured. The measurements were repeated five times.

3.5. Porosity measurement

The porosity (ε) of the cores was calculated using the relationship $\varepsilon = (1 - \rho_{app} / \rho_{true})$, where ρ_{app} is the apparent density of the cores and ρ_{true} is the true density. The apparent density of tablets was calculated from the geometrical data on the tablet measured with a screw micrometer and the mass of the tablet core measured by weighing. An AccuPyc 1330 helium pycnometer (Norcross, GA, USA) was used to determine the true volume of samples. The true density of a sample was then calculated from the mass and the true volume (Kumar et al. 2002).

3.6. Film coating of the tablets

One-kilogram batches of tablet cores were coated in a perforated pan coater (Manesty XL-014, UK). The coating solution was continuously fed to the spraying nozzle using a peristaltic pump with a flow rate of 10 to 15 g/min. The bed temperature was held at 40 ± 2 °C, and the inlet temperature varied from 50 °C to 56 °C. The atomizing air pressure was 1.2 bar and the rotational speed of the coating pan was set to 15 rpm. The total coating time was 45 min per batch. For each batch, 500 ml of coating solution was used, resulting in an approximately 80 μm thickness of film coating. After coating, the tablets were dried for 2 min at 40 °C and cooled for 5 min to 25 °C.

3.7. Measurement of mechanical properties of free films

A texture analyzer (TA-XT2-Stable Micro Systems, Godalming, UK) was used to determine the mechanical properties of free films under ambient conditions at 22 ± 1 °C and 40 ± 5% RH. The thickness of each film was measured at five different points and the films with a thickness of 80 to 90 μm were cut into 40 × 5 mm strips. Tensile grips were attached to the base platform and the crosshead of the texture analyzer. The samples were then placed between both grips and tightened to ensure that the film would not slip out during the test. The measurements were performed using a 5 kg load cell with 10 mm initial length of the film and 0.2 mm/s cross-speed. Measurements were repeated five times and the tensile strength at breaking point and the percent elongation at break were calculated as follows:

Tensile strength = Break force / AB, where A = thickness and B = width of films.

% elongation at break (%EB) = (L / L_0) × 100, where L_0 = original length of the sample and L = difference in the length at breaking point.

3.8. Adhesion measurement

The adhesion of film coatings to the tablet surface was measured using a tensile tester (TA.XT2-Stable Micro Systems). A tablet holder with a platform was custom-designed and fitted to the tester in place of the lower grip (Fig. 8A–C).

The film coating at the beveled edge of the tablet was carefully detached using a sharp blade and carefully mounted in the hole of the holder, which was secured with a metal clamp (Fig. 8A). The corresponding punch, which was previously used for tableting cores, was fixed with a special metal holder to the upper grip (Fig. 8C). Thus we ensured that the tablet shape and its position precisely fit the cavity of the upper punch. In this way we always provided the same position of the tablets during tests and improved the reproducibility of the measurements. Double-sided adhesive tape was then placed on the contact cavity of the upper punch, which was then carefully lowered onto the tablet surface, and a fixed force of 10 N was used to obtain firm contact of the tape to the film (Fig. 8B). After 5 s, the film was removed from tablet surface by lifting the upper arm at a constant speed of 1 mm/s. The force-time profiles were constructed during the measurements and adhesive strength as maximum peak of the curve determined from the data. For each set of measurements, 15 tablets were selected within 0.5% of the respective theoretical weight gain by coating to minimize the variation in film thickness.

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