

ON THE STRENGTH AND FRIABILITY OF SERIES PRODUCTS MANUFACTURED BY DIRECT COMPRESSION OF NON-METALLIC GRANULES

Oleksii Gubenia[1], Oleksandr Zomenko[2], Serhii Samarchuk[3] and Dumitru Mnerie[4]
[1] National University of Food Technologies Kyiv, Ukraine, gubena@meta.ua
[2] National University of Food Technologies, Kyiv, Ukraine, zemenkoaleksandr@gmail.com
[3] National University of Food Technologies, Kyiv, Ukraine, sergijsamarcuk@gmail.com
[4] Politehnica University Timisoara, Romania, dumitru_mnerie@yahoo.com

ABSTRACT: The aim Automation is essential in mass production. In the case of products obtained by direct compression of non-metallic powders, along with measures to increase productivity, there is a risk of reducing their quality. The present research represents an unconventional approach to the methodology of studying the friability of pharmaceutical tablets obtained by pressing the filling powders, in correlation with the working regime. The experiment used contributes to determining the impact of the compression cycles and the speed of the rotary table on the strength and friability of the tablets and other qualitative characteristics. The study enables the optimization of manufacturing technologies of pharmaceutical tablets, respecting the strict quality conditions imposed. The modernization of manufacturing technologies involves new approaches to scientific research in the field.

KEYWORDS: compression, strength, friability. tablets

1. INTRODUCTION

The quality of tablets post-compression affects subsequent stages of production, storage, and distribution in terms of mechanical integrity [23] and safety [13]. Thus, achieving high-quality standards at this stage directly influences the cost-effectiveness of tablet manufacturing.

During compression, deviations in tablet strength and friability may occur, impacting their manufacturability [22], particularly their integrity in subsequent operations such as coating, packaging, transportation, and storage [15, 29]. These deviations may compromise product safety [27], ultimately affecting production profitability. Tablet quality parameters are regulated by company standards as well as national [28] and international regulations [19].

Figure 1 illustrates the consequences of tablet friability during packaging – dusty streams of tablets being fed into the blister pack cavities. When tablets become dusty, they can get stuck in these streams and fail to enter the blister cavities, resulting in empty slots. Cleaning the equipment components to remove this dust requires time, which is undesirable in a production environment.

Tablet strength (hardness) [3] is a critical quality attribute, affecting integrity and resistance to wear during coating and packaging processes.

Tablet strength and friability are primarily influenced by formulation and compaction pressure. However, these properties are also affected by the operating parameters of compression equipment, specifically the press rotary table speed and the number of compression cycles [14]. Rotary table speed impacts both the rate of upper punch penetration into the die during compression and the duration that granules remain in their most compacted state under the compression cam (dwell time) [29]. Plastic deformation of granules in the die during compression is a rheological phenomenon that depends on pressure and time. Consequently, compression force and rotary table speed significantly influence tablet strength [32].

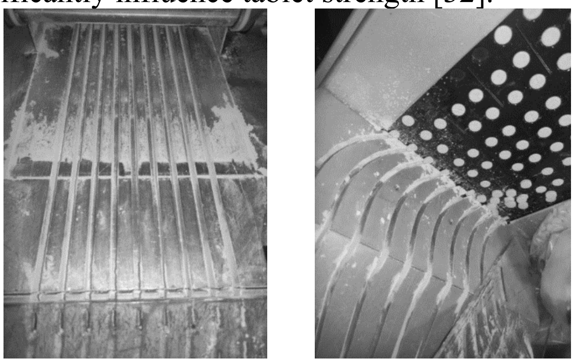

Figure 1. Dusty channels of the feeder in the blister packaging machine (own pictures)

The impact of these factors remains insufficiently described in scientific and reference literature, warranting further investigation.

Tablet strength is typically not regulated by external standards (it is non-pharmacopeial [17]) and is defined by the drug manufacturer [5]. However, deviations from the established strength should not exceed 5%. The diametral force at which tablets fracture typically ranges from 40 to 100 N, with strength as a derived measure depending on tablet size [17].

According to the harmonized European Pharmacopoeia, tablet friability should not exceed

1% [7]. However, some researchers consider this threshold too high and recommend friability values in the range of 0.3–0.5% [19].

Tablet strength and friability are influenced by formulation, compression force, equipment type and operating parameters, geometric characteristics, and surface condition of the tooling [6]. Given the numerous random factors, strength and friability are maintained through both formulation adjustments and equipment settings.

Most researchers focus on the dependency of tablet strength and friability on formulation, compression force, or compaction pressure. For instance, as compression force (and hence compaction pressure) increases from 8 to 30 kN, tablet strength rises from 0.2 to 1.4 kPa; at higher forces, further changes in tablet strength are minimal [18]. However, the experience of engineers and equipment operators suggests that the kinematic parameters of the press and its runtime affect tablet strength, friability, and other quality attributes. During multiple shifts, tablet strength may decline by over 10%, and friability may exceed 1% [14]. Similar defect rates occur at high rotary table speeds. Although the impact of these parameters on quality is minor compared to formulation and compaction pressure, the issue is scientifically and practically significant.

Therefore, further studies are required to explore the regulation of tablets' structural-mechanical and quality parameters by adjusting equipment operating modes and tooling surface conditions.

The aim of this research is to determine the effect of the number of compression cycles and the drum speed of the tablet compression machine on tablet strength and friability.

2. MATERIALS AND METHODS

The study focuses on evaluating tablet strength and friability. This research does not contain medical claims and is aimed solely at assessing the impact of operational parameters in the compression process on tablet strength and friability.

The strength parameters of two widely known pharmaceutical tablets were analyzed:

- Sample 1 was manufactured with the following excipients: citric acid monohydrate, potato starch, povidone, cocoa, calcium stearate, and active pharmaceutical ingredients (APIs): acetylsalicylic acid, paracetamol, and caffeine.
- Sample 2 was manufactured with the following excipients: potato starch, talc, calcium stearate, and API sodium metamizole.

The tablets were produced under industrial conditions using a Korsch XL 400 compression machine (Figure 2).

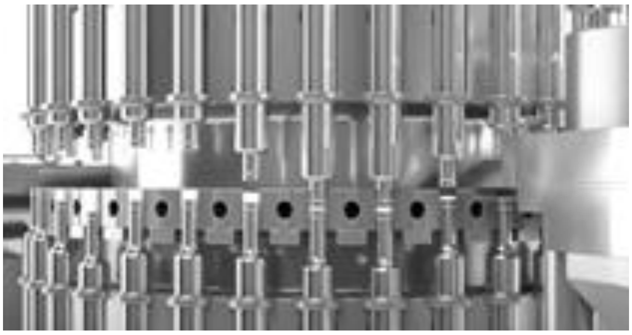

Figure 2. Dispensing and compression units of Korsch XL 400 compression machine

The Korsch XL 400 tablet press enables operation with a pre-compression force of up to 20 kN and a main compression force of up to 100 kN, achieving a maximum output of 338,000 tablets per hour at a maximum rotary table speed of 120 rpm.

A schematic diagram (histogram) of the press operation is shown in Aigure 3, illustrating the main stages: matrix filling with granulate, pre-compression and main compression of the tablet, and tablet ejection.

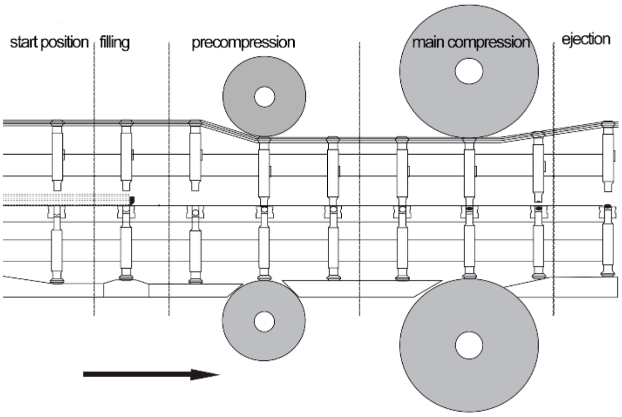

Figure 3. Schematic diagram of the Korsch XL 400 compression machine

During the investigation of tablet strength, samples were taken every eight hours of continuous operation of the tablet press (or every 28,200 finished tablets per die). For each analysis, 10 tablets were selected.

In the study of tablet friability, rotary table speeds of 35, 50, 65, and 80 revolutions per minute were utilized. A total of 12 tablets were used for each friability test.

Determination of tablet strength. The strength (or breaking limit) [7] of the tablet was determined using a widely accepted method in pharmaceutical practice: the tablet was compressed in a diametric direction, and the force P at which the tablet failed was measured. From the breaking force, the breaking limit σ_p was calculated.

The breaking limit of the tablet is defined as the ratio of the breaking force to the cross-sectional area of the tablet:

$$\sigma_p = \frac{P}{d \cdot h}, \text{Pa} \quad (1)$$

where P – is the breaking force (N), d – the diameter of the tablet (m), and h – the height of the tablet (m).
In this study, the breaking force and strength of the tablet were determined using the PTB-M 300 N Pharma Test device.
The working mechanism of the device consists of two jaws oriented toward each other, which move in a horizontal plane to compress the tablet in a diametric direction. The device's accuracy is 1 N, and each test was repeated 10 times.

Determination of tablet friability. According to the standards accepted in the pharmaceutical industry, tablet friability was assessed using the "ERWEKA TAR II" device, which features a rotating wheel with a single blade.
The working component of the device is a cylindrical drum made of transparent polymer material, with an internal diameter of 283–291 mm and a rotation speed of 25±1 revolutions per minute. Inside the chamber, a blade of specified shape creates a lifting and dropping motion for the tablets. During the drum's rotation, the tablets fall from a height of 156±2 mm (or 6 inches).
Initially, 10 tablets are dusted, weighed, and placed in the drum. The lid is closed, and the device is operated for 4 minutes. After this period, the tablets are weighed again.
The friability index F, % is determined with:

$$F = 100 - \frac{P_{start} - P_{fin}}{P_{start}} \cdot 100 \qquad (2)$$

where P_{start}, P_{fin} – are the mass of the tablets before and after the friability test, respectively.

3. RESULTS AND DISCUSSION

Assumptions made during experimental planning and data analysis

The active pharmaceutical ingredient (API) does not significantly affect the strength and friability parameters.
Changes in tablet strength and friability, like other quality indicators, depend not on the rotary table speed but on the number of compression cycles – that is, how many tablets were produced by a single press pair punch-die (Figure 4).
The parameter "Number of Compression Cycles" is convenient for analyzing and comparing results, especially if experiments were conducted on different presses with varying rotary table speeds or static (crank) presses. However, the parameter "Rotary table Speed" can sometimes be practical in a production setting, providing a more intuitive understanding of the process. It should not be disregarded that rotary table speed may also influence the final quality of the tablets. For instance, changes in speed alter the motion dynamics of the punches in the die, as well as vibration parameters in the equipment and press pair.

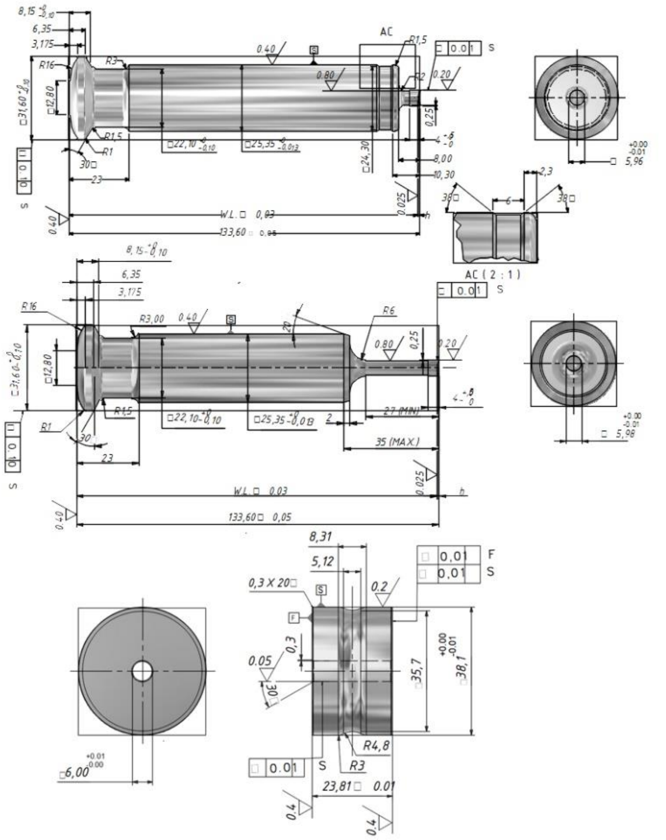

Figure 4. Construction of punch and die which were used for tablet compression

The strength and friability parameters are influenced not by rotary table speed, but by the velocity of the punches induced by it, which affects both the pressing and ejection speeds of the tablets.

Influence of compaction degree on tablet strength

The effect of compaction degree (or tablet mass) on tablet strength has been sufficiently studied. In our case, three distinct phases can be identified: a preliminary compression phase, where strength changes only minimally; an intensive compression phase, during which strength increases rapidly; and a tablet fracture phase, in which strength decreases as compaction pressure continues to rise (Figure 5).
In the third zone, the strength data are obtained with a significant spread. This can be explained by the fact that with a high degree of compression, the structure of the material is destroyed, as well as significant frictional forces arise when pushing the tablet out of the die, which lead to the destruction of the lateral surface of the tablet.
The strength of the tablet in this study was higher compared to the results of other authors [29]. This can be explained by the fact that the tableting material was subjected to dry granulation compared to wet granulation in most other studies.

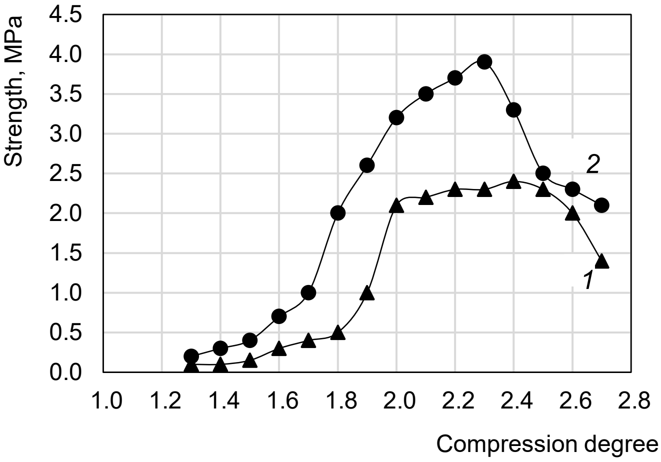

Figure 5. Influence of compaction degree on tablet strength. 1 – Sample 1; 2 – Sample 2.

Influence of number of compression cycles on breaking stress of tablets

For two tablet samples, a reduction in strength of up to 10% was observed over three hundred thousand compression cycles, which corresponds to 80 hours of tablet press operation.

As the number of tablet compression cycles increased from 28,000 to 280,000 – approximately 8 to 80 hours of press operation – the breaking stress (strength) of sample 1 decreased from 102 N to 91 N, and that of sample 2 decreased from 152 N to 140 N (Figure 6).

The reduction in tablet strength followed a parabolic trend: during the initial 100,000 to 150,000 cycles (30 to 35 hours of press operation), the decline was minor, but it accelerated thereafter.

Over time, the strength of the tablets decreased by more than 5%, indicating that to ensure consistent product quality, the process should be halted and measures taken to restore initial strength. In this study, it is advisable to pause the process from 200,000 to 250,000 cycles, or approximately at from 60 to 70-hour mark of press operation.

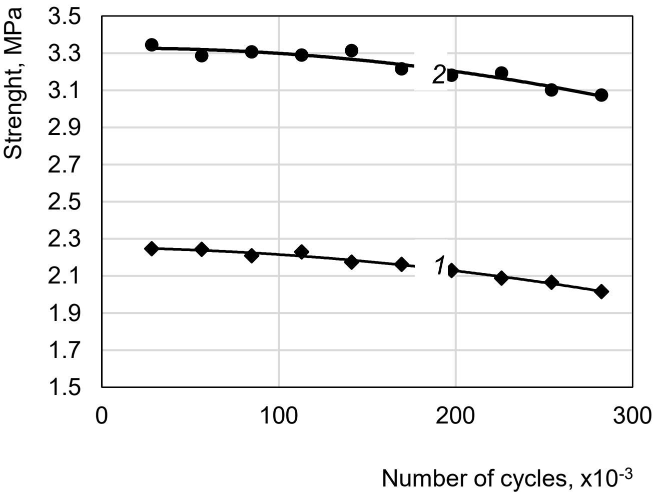

Figure 6. Influence of the number of cycles on tablet strength. 1 – Sample 1; 2 – Sample 2.

Manufacturers must ensure stable tablet strength; however, it decreases during prolonged operation of the tablet press. One well-known method to maintain consistent strength is to monitor the condition of the die and punch surfaces, particularly through periodic polishing.

Preliminary observations in this experiment indicated that after polishing the working surfaces of the punches and dies, the breaking stress (strength) of the tablets returned to initial values within 7–10 cycles. However, beyond this point, other disruptive factors emerge, leading to a reduction in the initial strength of the tablets. This issue requires further investigation.

In this study, it is suggested to polish the compression tools after 48 hours of operational time.

The reduction in tablet strength during extended press operation can be attributed to the formation of a buildup on the surface of the compression tools, which increases the frictional force (stress) and the ejection pressure of the tablet in the die (Figure 7).

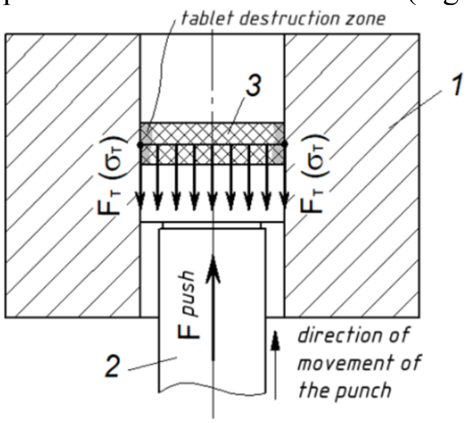

Figure 7. Forces acting on the lateral surfaces of the tablet during ejection from the die: 1 – Die; 2 – Punch; 3 – Tablet. *F*T – Frictional force (N); σ – Frictional stress (Pa). Gray zone – area of intense destruction of the tablet's lateral surfaces.

As a result, the surface layers of the tablets become less robust, and the density distribution of the tablets in height and width becomes inconsistent.

Influence of rotary table speed on tablet friability parameters

Information gathered from specialists operating tablet manufacturing equipment, along with personal observations, indicated that tablets produced at high rotary table speeds exhibit lower strength and higher friability. The optimal rotary table speed of the tablet press is typically determined based on production experience and validation protocols for the manufacturing process.

As the rotary table speed of the tablet press increases from 35 to 80 revolutions per minute, the percentage of friability for sample 1 rises from 0.15% to 1.24% (Figure 8).

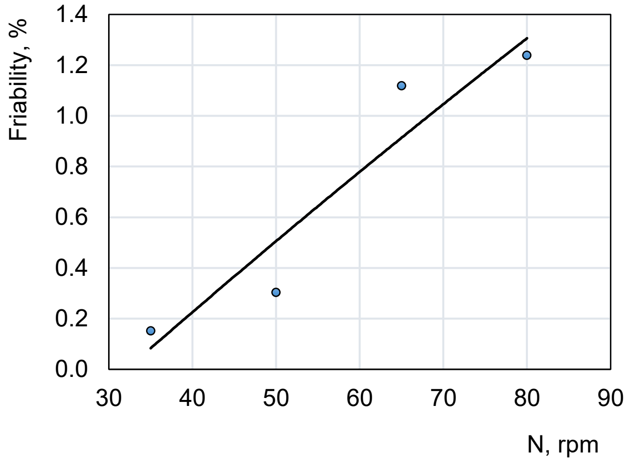

Figure 8. Influence of rotary table speed on tablet friability.

According to the aforementioned assumption, friability is influenced not by the rotary table speed but by its derivative – the velocity of the punches in the die and, consequently, the ejection speed of the tablet.

As with tablet strength, the relationship depicted in Figure 8 can be explained by the fact that at high ejection speeds, the external layer of the tablet is compromised due to significant frictional forces. This outer layer experiences excessive wear during subsequent processing and finishing operations. Such defects negatively affect coating applications in drum-type machines and fluidized bed systems, as well as during transportation between equipment and while packaging tablets in blister packs.

Other studies have reported the impact of sliding speed on the coefficient or stress of friction [29]. For intermediate products and food items with high adhesion strength (such as bread, meat products, and cheeses), the frictional (or adhesive) stress significantly increases at high sliding speeds, which affects their mechanical processing by cutting. Conversely, for products with low moisture content, the effect of sliding speed on friction (adhesion) stress is negligible.

Further research is needed to explore additional factors affecting friability, including vibration in the press tools, surface roughness of the die and punches, and methods and depth of periodic polishing.

Influence of number of compression cycles on tablet friability

An increase in friability was observed with the rise in working cycles: at the beginning of the experiment, the friability percentage ranged from 0.18% to 0.30%, while at the end of the experiment, it increased to 1.19% to 1.24% (Figure 9).

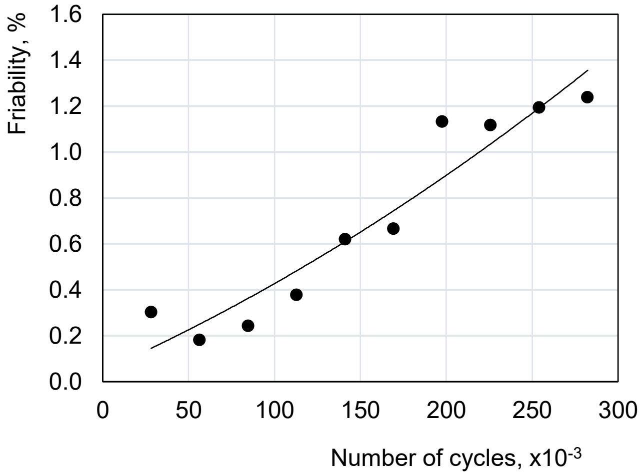

Figure 9. Influence of the number of working cycles on tablet friability.

Influence of rotary table speed on tablet strength

In manufacturing conditions, a rational pressing speed is typically established for each type of tablet, which depends on the rotary table speed of the tablet press. At high pressing speeds, the strength of the tablet decreases.

During the experiment, within the rotary table speed range of 35 to 80 revolutions per minute, a nearly linear relationship between rotary table speed and tablet strength was observed (Figure 10).

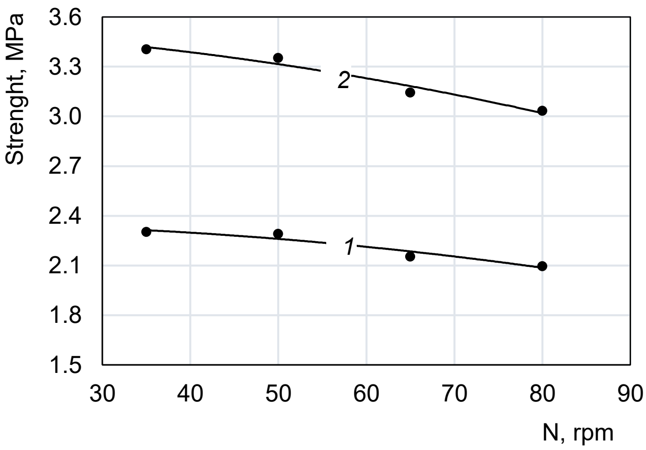

Figure 10. Influence of rotary table speed of the tablet press on tablet strength.
1 – Sample 1; 2 – Sample 2.

This phenomenon can be attributed to the fact that at high pressing speeds, the tablet structure does not have adequate time to form, and elevated ejection speeds increase frictional forces, leading to the destruction of the tablet's outer layers. Within the examined rotary table speed range, the strength of the tablets decreases by up to 20%. Given the necessity to maintain stable quality parameters, it is inadvisable to exceed a rotary table speed of 50 revolutions per minute.

It is also likely that the tablet strength is influenced by the dwell time during which the upper and lower punches remain stationary. The dwell time is affected by the increase in the flat surface area of the punch head that contacts the pressing roller. However, it should be noted that the curved portion of the punch head responsible for punch movement decreases, which leads to increased speed and acceleration of the punch. Higher pressing speeds may negatively impact tablet quality.

4. CONCLUSIONS

Operational parameters. The operational parameters of the rotary compression machine influence tablet strength. Within the working range of the rotary table speed from 30 to 80 revolutions per minute, tablet strength can decrease by up to 10%. This is attributed to changes in pressing speed and reduced dwell time of the tablet in the die.

Compression cycles. The number of compression cycles (number of tablets produced) in the die-punch pair affects tablet strength: after 300,000 cycles, the tablet loses on average, up to 8% of its strength. This is due to product adhesion to the die and punch surfaces, increasing their roughness and consequently raising the friction coefficient and adhesion strength. As a result, the outer layer of the tablet exhibits lower strength and undergoes intense degradation.

Tablet friability. With an increase in rotary table speed from 30 to 80 rpm, tablet friability increases from 0.2% to 1.2%, exceeding the regulated pharmacopeial (1%) and recommended (0.5%) limits. This is due to reduced dwell time in the die and increased ejection speed, which weakens the outer layers of the tablet. High friability leads to poorer quality in the application of protective coatings, increased rejection rates during coating, and dust accumulation in the blister machine feeder.

Rotary table speed limitations. The increases in strength and friability impose limitations on the rotary table speed of the tablet press. For the tablets used in this study and the Korsch XL 400 tablet press, the optimal rotary table speed is 50 rpm. Increasing the rotary table speed, and thus productivity, is feasible through more frequent polishing of the surfaces of the dies and punches.

5. REFERENCES

1. Adeleye O. (2019), Relationship between compression pressure, mechanical strength and release properties of tablets, *Polymers in medicine*, 49(1), pp. 27–33, https://doi.org/10.17219/pim/111888
2. Augsburger L.L., Hoag S.W. (2008), Pharmaceutical dosage forms - tablets, third edition, Taylor & Francis Grou.
3. Commission BP (2021), British pharmacopoeia 2021, Stationery Office.
4. Byrn S., Futran M., Thomas Hayden., Jayjock Eric., Maron Nicola., Meyer Robert., Myerson Allan., Thien Michael., Trout Bernhardt (2015), Achieving Continuous Manufacturing for Final Dosage Formation: Challenges and How to Meet Them. May 20–21, 2014 Continuous Symposium, *Journal of Pharmaceutical Sciences*, 104(3), pp. 792-802, https://doi.org/10.1002/jps.24247
5. CDER (Center for Drug Evaluation and Research) (2015), Guidance for industry: size, shape, and other physical attributes of generic tablets and capsules, United States Food and Drug Administration.
6. Çelik M. (2013), *Pharmaceutical Powder Compaction Technology*, CRC Press.
7. European pharmacopoeia. Available at: https://www.edqm.eu/en/web/edqm/european-pharmacopoeia.
8. ERWEKA GmbH (2024), TAR II - advanced friability and abrasion tester - ERWEKA GmbH. *Home - ERWEKA GmbH*. Available at: https://www.erweka.com/products/physical-testers/friability-tester.html
9. Etzler F.M., Bramante T., Deanne R., Sienkiewicz S., Chen F. J. (2011), Tablet tensile strength: an adhesion science perspective, *Journal of Adhesion Science and Technology*, 25(4–5), pp. 501–519, https://doi.org/10.1163/016942410X525687.
10. Giannis K., Schilde C., Finke J.H., Kwade A. (2021), Modeling of High-Density Compaction of Pharmaceutical Tablets Using Multi-Contact Discrete Element Method, *Pharmaceutics*, 13(12), 2194, https://doi.org/10.3390/pharmaceutics13122194
11. Goh H., Sia Heng P., Liew C. (2019), The effects of feed frame parameters and turret speed on mini-tablet compression, *Journal of Pharmaceutical Sciences*, 108(3), pp. 1161–1171, https://doi.org/10.1016/j.xphs.2018.09.005.
12. Goots V., Guts O., Gubenia O. (2016), Reodynamical theory of viscous-elastic system deforming, Proceedings of University of Ruse, 55(10.2), pp. 18-22.
13. Gubenia O., Goots O. (2010), Modeling of cutting of food products, *Journal of EcoAgriTourism*, 1, pp. 67–71.
14. Herasymenko D., Zomenko O., Gubenia O. Influence of tablet press rotor speed on tablet abrasion performance, *90th International scientific conference of young scientist and students "Youth scientific achievements to the 21st century nutrition problem solution"*, April 11–12, 2024, NUFT, Kyiv.

15. Natoli D., Levin M., Tsygan L, Liu L. (2017), Development, Optimization, and Scale-Up of Process Parameters, In: Developing Solid Oral Dosage Forms, Ed.: Yihong Qiu, Yisheng Chen, Geoff G.Z. Zhang, Lawrence Yu., Rao V. Mantri, pp. 917–951, https://doi.org/10.1016/B978-0-12-802447-8.00033-9.
16. Peeters E., Silva A.F.T., Fonteyne M., De Beer T., Vervaet C., Remon C. (2018), Influence of extended dwell time during pre- and main compression on the properties of ibuprofen tablets, *European journal of pharmaceutics and biopharmaceutics*, 128, pp. 300–315, https://doi.org/10.1016/j.ejpb.2018.05.007.
17. Pharmaeducation (2024), *Quality control tests of tablets or Evaluation of tablets,* Available at: https://pharmaeducation.net/quality-control-tests-of-tablets-or-evaluation-of-tablets/.
18. Pitt K., Heasley M. (2013), Determination of the tensile strength of elongated tablets, *Powder technology*, 238, pp. 169–175, https://doi.org/10.1016/j.powtec.2011.12.060.
19. Podczeck F. (2007), Methods for the practical determination of the mechanical strength of tablets – From empiricism to science, *International journal of pharmaceutics*, pp. 214–232, https://doi.org/10.1016/j.ijpharm.2012.06.059.
20. Salawi A. (2022), Pharmaceutical coating and its different approaches, a review. *Polymers*, 14(16), pp. 3318, https://doi.org/10.3390/polym14163318
21. Siiriä S.M. Antikainen O., Heinämäki J., Yliruusi J. (2011), 3D simulation of internal tablet strength during tableting, *AAPS PharmSciTech*, 12(2), pp. 593–603, https://doi.org/10.1208/s12249-011-9623-0
22. Sinka I.C., Pitt K.G., Cocks A.C.F. (2007), Chapter 22. The strength of pharmaceutical tablets, *Handbook of Powder Technology,* 12, pp. 941–970, https://doi.org/10.1016/s0167-3785(07)12025-x
23. Swarbrick J. (2007), Encyclopedia of pharmaceutical technology: Volume 6, Taylor & Francis Group, 2007.
24. Tye C.K., Sun C., Amidon G.E. (2005), Evaluation of the effects of tableting speed on the relationships between compaction pressure, tablet tensile strength, and tablet solid fraction, *Journal of Pharmaceutical Sciences*, 94(3), pp. 465–472, https://doi.org/10.1002/jps.20262
25. Gordiienko O.I., Vronska L., Melnyk O.A., Groshovyi T.A. (2015), Current state of creation, production and research of tablet medicinal products, *Pharmaceutical Review*, 1, https://doi.org/10.11603/2312-0967.2015.1.3780
26. Sivetskyi V., Shvachko D. (2023), Presove obladnannia, KPI im. Ihoria Sikorskoho, Kyiv
27. Tryhubchak O. (2018), Doslidzhennia optymalnykh umov vyhotovlennia tabletok kysloty atsetylsalitsylovoi z atorvastatynom, Liky Ukrainy, 2(35), pp. 7–10.
28. Trudko S.S., Gubenia O.O., Desyk M.G., Gavva O.M. (2024), Packaging of medicines in blister packs, *Packaging,* 3, pp. 28–31.
29. Oloniyon F. Akande, James L. Ford, Philip H. Rowe, Michael H. Rubinstein The Effects of Lag-time and Dwell-time on the Compaction Properties of 1: 1 ParacetamoUmicrocrystalline Cellulose Tablets Prepared by Pre-compression and Main Compression Journal of Pharmacy and Pharmacology, Volume 50, Issue 1, January 1998, Pages 19–28, https://doi.org/10.1111/j.2042-7158.1998.tb03300.x