Relationship Between Tableting Motion and Tablet Hardness in Compression Molding

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Abstract: A tableting machine is used to form powders into tablets. It is well known that the quality of tablets formed by tableting machines varies greatly depending on the compression conditions, such as compression velocity and compressive force. It is of industrial importance to clarify how compression conditions affect the properties of the formed tablets. In this research, we manufactured a tableting machine with an upper and lower pestle that can be arbitrarily operated, and the aim of this research is to clarify the relationship between the tableting conditions and the property of the formed tablets. In this experiment, we change the driving pestle as the tableting condition, measure the formed tablet hardness, and discuss the relationship between them.

1 INTRODUCTION

A tableting machine is a machine used to make tablets from powder by compression molding. This machine has been widely used mainly in the pharmaceutical industry. It is expected to be applied in the food and material industries as well, due to its advantages such as reduced transportation and storage costs by reducing the volume of powder to tablets (Kamiya, 2022), (Brewin, 2008). Typical performance requirements for tableting machines include high-velocity molding for improve productivity and high-hardness molding to prevent disintegration. In general, it has been confirmed that tablet hardness increases when compression velocity is reduced (Mohan, 2012). However, decreasing the velocity is accompanied by a decrease in productivity. Therefore, the development of a technology that can both improve productivity and increase hardness is a problem (Kamiya, 2022). Conventional researches have attempted to solve this problem by using the method of precompression followed by main compression (Patel, 2006) or by adding additives such as excipients to the powder (Kamiya, 2012). However, it has been confirmed that additives lack physical safety (Bharate, 2010).

We have developed a single-shot tableting machine with an upper and lower pestles that can be arbitrarily operated until now, and we have performed compression molding with the upper pestle as the driving pestle. We considered that the tablet hardness could change by the direction of the compressive force acting on the powder. In this research, the compression molding was performed in the following three patterns: the upper pestle compression using the upper pestle as the driving pestle, the lower pestle compression using the lower pestle as the driving pestle and the double pestle compression using both pestles as the driving pestle. The hardness of tablets formed by three different motions of the driving pestle is compared.

2 EXPERIMENTAL DEVICES

2.1 Tableting Machine

Figure 1 shows the overall structure of a tableting machine. There are two types of tableting machines: the single-shot type and the rotary type. In this research, the single-shot type was adopted because

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Table 1: Performance of each servo motor of tableting machine and hardness tester.

Specification Items	Upper	Lower	Hardness tester
Rating output [kW]	0.36	0.4	0.05
Rating current [A]	2.8		1.1
Rating Torque [N・m]	1.15	1.27	0.16
Instantaneous maximum stall torque [N・m]	4.8		0.48
Instantaneous maximum stall current [A]	10.8		4.7
Torque constant [N・m/A]	0.524		0.1021
Rating rotation speed [min^{-1}]	3000		

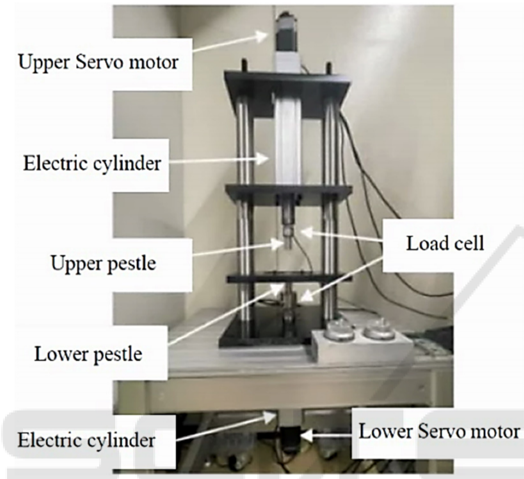


Figure 1: Tableting machine.

the purpose of tableting is prototyping and the tableting conditions can be changed.

The tableting machine consists of a PMAC as the host device, and commands are sent from the motion program on the PMAC to the servo amplifier, which drives the servo motor. The tableting machine is controlled by a semi-closed-loop system using a rotary encoder with a resolution of 17 bits installed in the servo motor. Data capture is performed at a setting of 4 kH (250 ms/data). Each servo amplifier is connected to the Eather CAT network environment to improve synchronization performance of each axis.

The tableting machine is installed with a load cell between the pestle and the electric cylinder to measure the compressive force. The load cells have a capacity to measure compressive forces of 5 kN for the upper pestle and 10 kN for the lower pestle.

2.2 Hardness Tester

In our laboratory, we have manufactured a hardness tester and use it to measure tablet hardness. Figure 2 shows the overall structure of the hardness tester. On the compression side of the hardness tester, a servo motor and an electric cylinder connected by a coupling are installed, and a terminal for compressing tablets is attached to the end of the electric cylinder. On the measurement side, a load cell was fixed to the stage, and a terminal for supporting the tablet was attached to the end of the load cell. The side of the tablet was pressed in with the compression terminal, and the force at break was measured by the load cell. The compression speed was 1 mm/s.

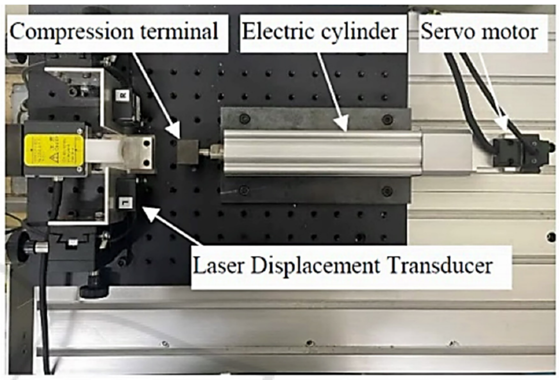


Figure 2: Hardness tester.

3 EXPERIMENT CONDITIONS

The sample is weighed using an electronic balance with an accuracy of 1.9995 g to 2.0004 g. The sample is placed in the mortar, and compression molding is performed using a driving pestle. The motion method of the pestle is a motion numerical control using a host device. Figure 3(a)~(c) shows the compression processes (the process before driving pestle compression where the motion of the driving pestle starts, the compression process where the distance between the pestles is minimized, and the pressure release process where the compressive force is removed) for each of upper pestle compression, lower pestle compression and double pestle compression.

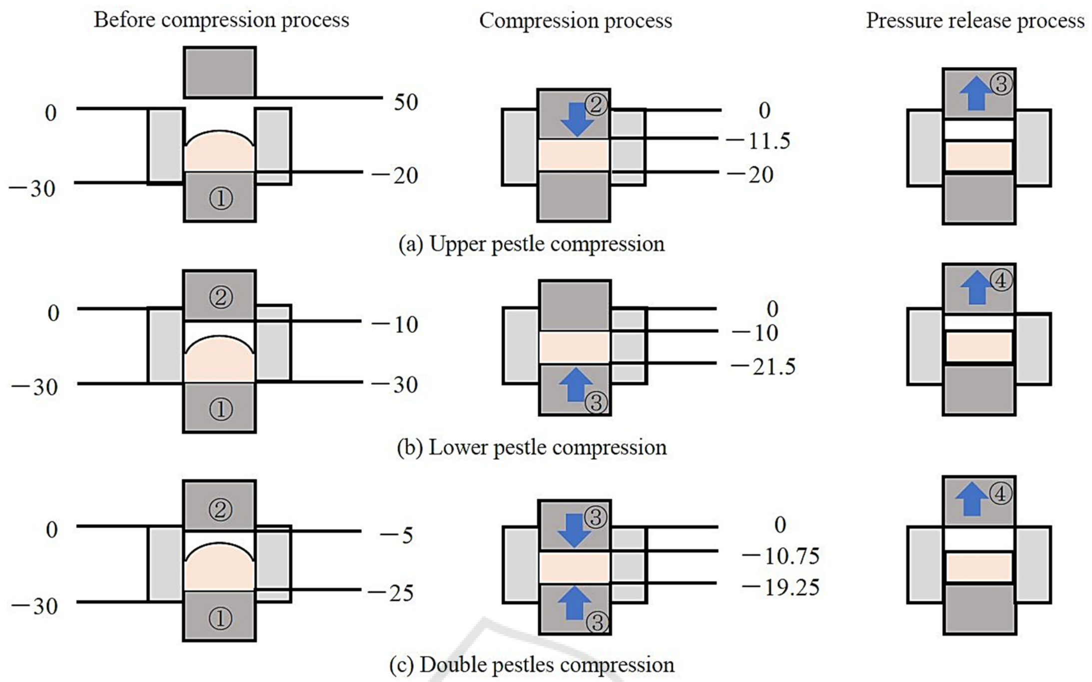


Figure 3: Compression process.

In the upper pestle compression, the lower pestle is held at a position -20 mm from the upper edge of the mortar and the powder is placed into the mortar (before the driving pestle compression process). The upper pestle is compacted downward direction from a position 50 mm to a position -11.5 mm (Compression process).

In the lower pestle compression, the lower pestle is held at a position -30 mm from the upper edge of the mortar and the powder is placed into the mortar. The upper pestle is moved downward from a position 50 mm and held in place at a position -10 mm (before the driving pestle compression process). The lower pestle is compacted upward direction from a position -30 mm to a position -21.5 mm (Compression process).

In the double pestles process, the lower pestle is held at a position -25 mm from the upper edge of the mortar and the powder is placed into the mortar. The upper pestle is moved downward direction from the position 50 mm and held at the position -5 mm (before the driving pestle compression process). The upper pestle compacted at the same time from a position -5 mm to a position -10.75 mm and the lower pestle from a position -25 mm to a position -19.25 mm (Compression process).

The optional motion of the dynamic pestle adopts a two-stage compression molding process, in which compression molding is performed at a constant velocity of 1 mm/s and 10 mm/s, respectively, starting from a position where the distance between the pestles is 10.5 mm. Pressure release velocity is a constant velocity of 50 mm/s. After compression molding, tablet height is measured using a micro laser distance measurement sensor and tablet weight is measured using an electronic balance. The tablets were then compacted from the side using a tablet hardness tester to break the tablets, and the hardness was calculated by measuring the value at the time of breaking using a load cell.

4 EXPERIMENTAL RESULTS

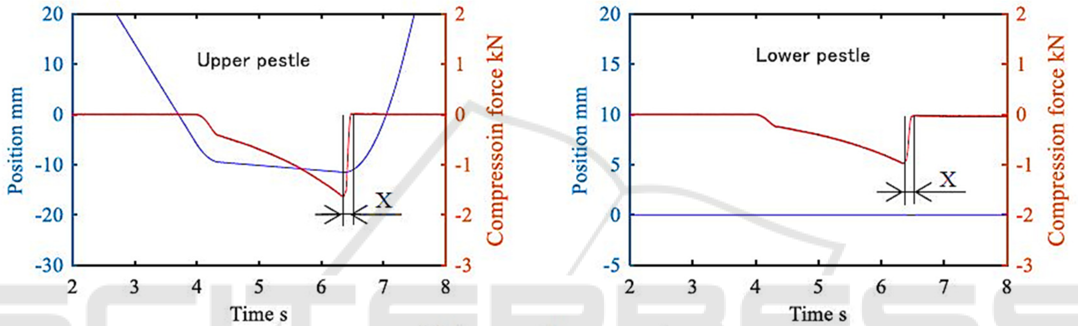
Table 1 summarizes the experimental results. Where, U-01 means that the upper pestle was used as the driving pestle at a compression velocity of 1 mm/s. The table shows that slower compression velocitys resulted in higher tablet hardness without depending on the tableting motion.

The profile of the compression process (pestle position and compressive force) is shown in Figure 4. The amount of elastic recovery is an important data during tableting. In this time, the amount of elastic recovery is defined as X, which is the distance from the maximum compression position until no force is detected. Elastic recovery in compression molding occurs either inside the mortar immediately after compression molding or outside the mortar when the

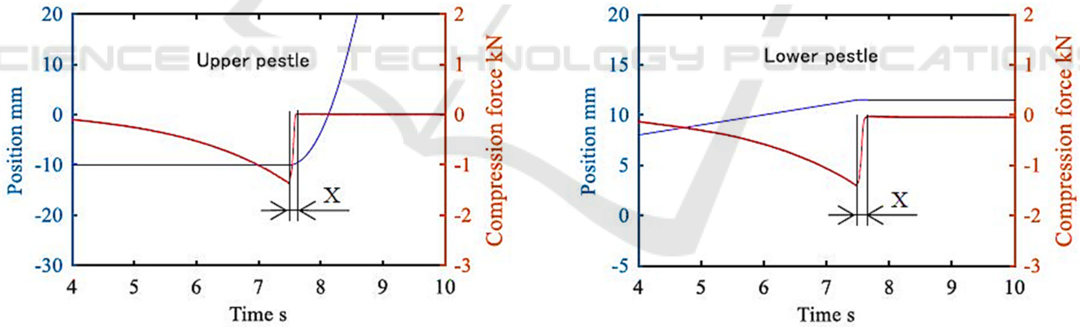
Table 2: Three times average experimental results.

Test condition No.	Powder weight g	Tablet weight g	Tablet height mm	Tablet hardness N	Compressive force kN	Elastic recovery mm
U–01	2.0003	1.9989	8.88	13.7	2.65	0.283
L–01	1.9999	1.9989	8.90	15.8	2.68	0.273
D–01	2.0001	1.9950	8.87	12.8	2.80	0.287
U–10	2.0000	1.9977	8.80	10.8	2.56	0.286
L–10	2.0001	1.9973	8.89	13.2	2.57	0.277
D–10	1.9999	1.9926	8.92	10.9	2.67	0.290

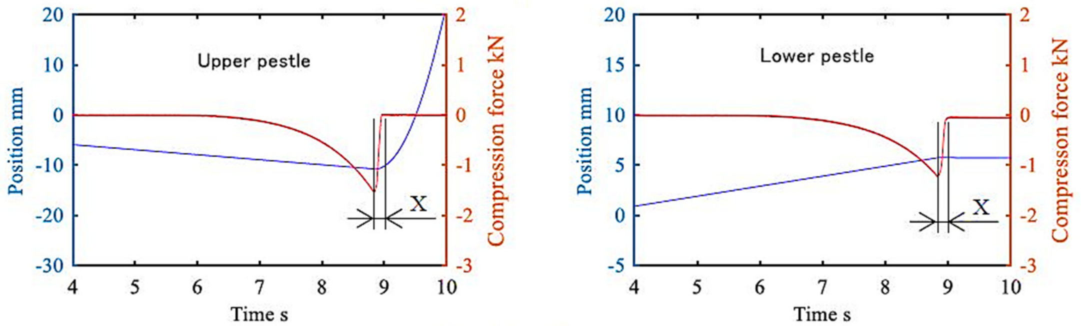
[U–01]→Upper pestle compression and compression velocity 1mm/s



(a) Upper pestle compression



(b) Lower pestle compression



(c) Double pestle compression

Figure 4: Compression process of elastic recovery (1 mm/s).

tablet is removed from the mortar (Rahul, 2010). We measured the amount of elastic recovery inner mortar.

Table 1 also shows the amount of elastic recovery. Regarding the relationship between the compression velocity and this amount, it can be seen that the faster the compression velocity, the larger the amount of elastic recovery, and the powder cannot be compacted. As for the tableting motion, this amount is smaller in the order of double pestles, upper pestle, and lower pestle, indicating that the smaller the amount of elastic recovery, the higher the hardness of the tablet. It is considered to be more compressed in this sequence.

5 CONCLUSIONS

In this research, an experiment was conducted to compare tablet hardness by three types of pestle motions in powder compression molding. As a result, it was found that the highest tablet hardness can be obtained by lower pestle compression. Tablet hardness is considered to be related to the amount of elastic recovery of the tablet that occurs inside the mortar during compression molding. In the future,the relationship between tablet hardness and elastic recovery will be further investigated by applying various tableting conditions.

On the other hand, the relationship between compressive force and hardness is not clear. It is affected by the particle size, particle shape, and particle size distribution of the powder (Changouan, 2005). In addition, various factors such as air flow in the mortar during compression molding and temperature and humidity have been reported to have an effect (Kremer, 2006), (Casettari, 2016). We are also going to discuss the relationship between compressive force and hardness or elastic recovery.

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