Effect of crosshead speed on retentive force measured using a device specified in ISO 13017:2020

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Introduction

Retentive force is one of the most important properties of dental magnetic attachments[1)]. Retentive force testing applies similar principle to tensile test. Tensile (pulling) forces applied to a dental magnetic attachment until separation of the attachments occurs are measured[2)]. In a tensile test, the appropriate crosshead speed is specified based on the type of material used[3-5)]. In 2009, Ogawa *et al.* evaluated the effect of crosshead speed on the retentive force of a magnetic attachment, and concluded that there was no statistically significant difference in retentive forces measured at crosshead speeds of 0.5 – 5.0 mm/min[6)]. Based on the result of this research; International-Organization-for-Standardization (ISO) 13017 published in 2012 specified that the retentive force should be measured at a crosshead speed of 5.0 mm/min or less[7)]. However, it was still difficult to measure retentive force with acceptable accuracy and repeatability. This necessitated the development of a device for measuring retentive force with sufficient accuracy and repeatability. Thereafter, ISO 13017 amendment 1 was published in 2015 with detailed specifications of a device suitable for measuring the retentive force of dental magnetic attachments[8)].

An SC2/WG22 meeting under ISO/TC106 technical committee responsible for formulating a standard that combines ISO 13017 and its amendment 1 started in 2017[9)]. In 2018 at the Milan meeting; a concern that the retentive force measured at a crosshead speed of 5.0 mm/min was too fast emerged. The recommendation was to maintain a crosshead speed of 2.0 mm/min or less. As a result, ISO 13017 published in 2020 specified that the crosshead speed should be 2.0 mm/min or less[2)]. However, there is no scientific evidence found that confirms the recommended cross head speed value of 2.0 mm/min. The study done by Ogawa *et al.* in 2009 was done before specifications on the measuring device, in accordance with ISO, were developed. Furthermore, the study only focused on closed magnetic circuit utilized by most of the dental attachments. Open magnetic circuit is also utilized in some dental magnetic attachments albeit rare. There are no other studies found which investigate the effect of crosshead speed on retentive force values. It is important to investigate the effect of crosshead speed on retentive force of both closed and open magnetic circuit attachment done on a device that matches the ISO 13017:2020 specifications.

Objective

The aim of this study was to investigate the effect of crosshead speed on retentive force value measured using a device specified in ISO 13017:2020.

Materials and Methods

Magnets and dental magnetic attachment

Magnets portray an open magnetic circuit. They form part of the components used to make dental magnetic attachments. Two types of magnets and one type of magnetic attachment were used in this study. One pair of cylindrical neodymium magnets (Nd-Fe-B: 4 mm in diameter and 2 mm in height, Trusco) and one pair of samarium-cobalt magnets (Sm-Co: 4 mm in diameter and 2 mm in height, Magna) were prepared. GIGAUSS D600 (GC), a dental magnetic attachment that utilizes closed magnetic circuit, was used in this study. Each set of magnets of the same type and the magnetic attachment was subjected to retentive force measurement five times.

Test procedure for measuring retentive force

The retentive force measuring device used in this study matches the basic description in ISO 13017:2020. It was connected to a digital force gauge (ZPS, Imada). Retentive forces were measured and recorded in accordance with the test procedure stipulated in ISO 13017:2020 and retentive force curves generated. Crosshead speed was controlled by a universal testing machine (AGS-5kNG, Shimadzu).

Crosshead speed

Measurements were done at 19 different crosshead speeds (mm/min): 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 50, 100, 200, 300, 400 and 500. The retentive force value attained at the lowest speed of 0.5 mm/min was used as a reference value. This concept was applied in both scenarios of magnet combinations and magnetic attachment. The obtained data in comparison to reference value was statistically analyzed using ANOVA and Tukey's HSD test ($\alpha = 0.05$).

Results and Discussion

1. Measured values of retentive force and crosshead speeds

Measured values of retentive force to crosshead speeds are shown in Figs. 1-3. There was no significant difference ($p>0.05$) in the measured values obtained at crosshead speed of 0.5 – 50 mm/min in each combination. On the other hand, the measured values at 100 mm/min and more were significantly higher ($p<0.01$) than those obtained at 0.5 mm/min.

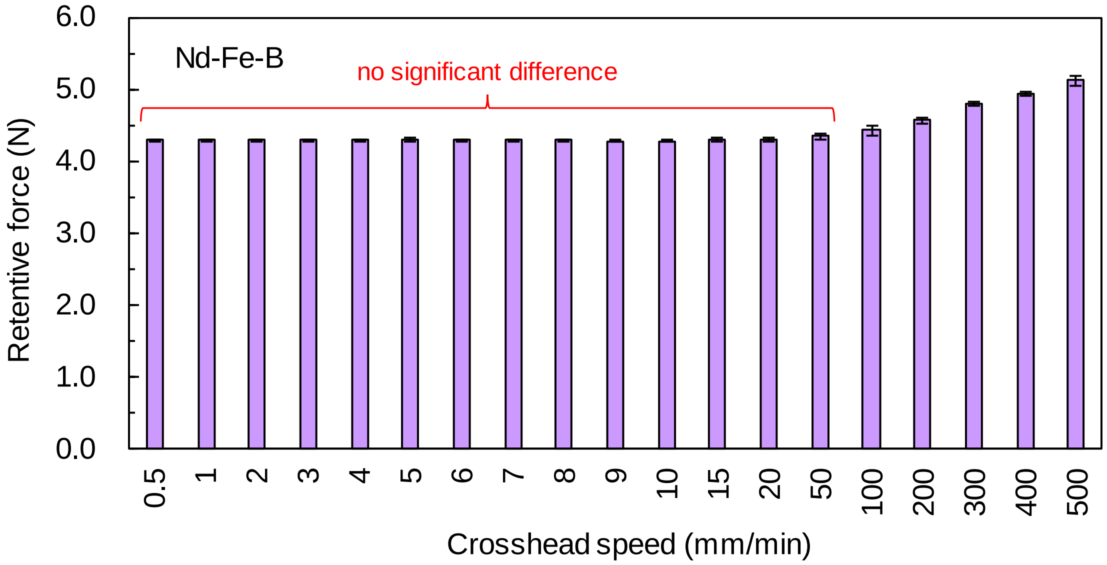


Fig. 1 Measured values of retentive force to crosshead speeds in Nd-Fe-B magnets

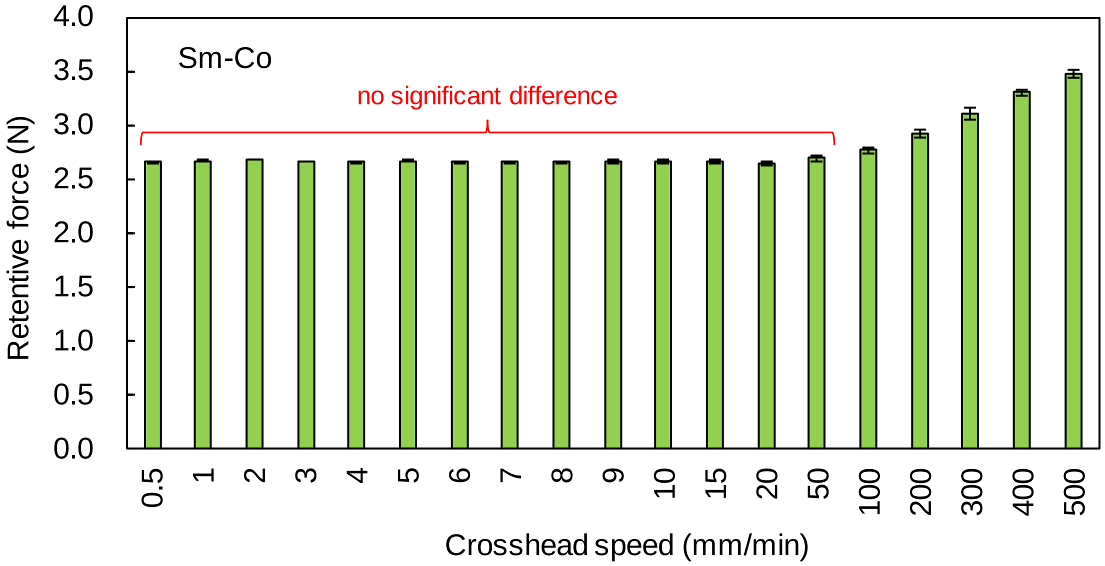


Fig. 2 Measured values of retentive force to crosshead speeds in Sm-Co magnets

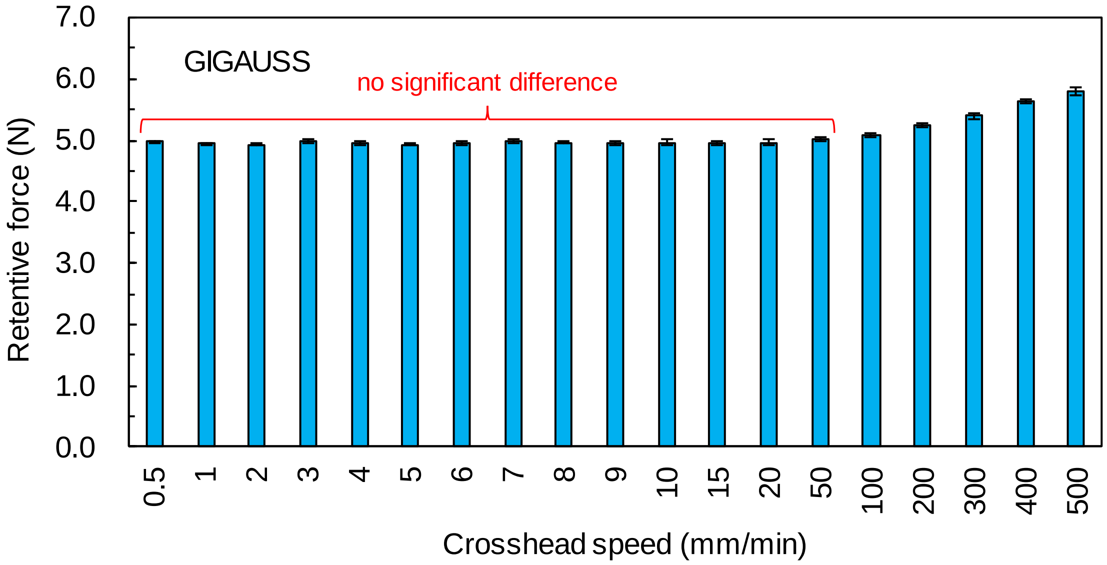
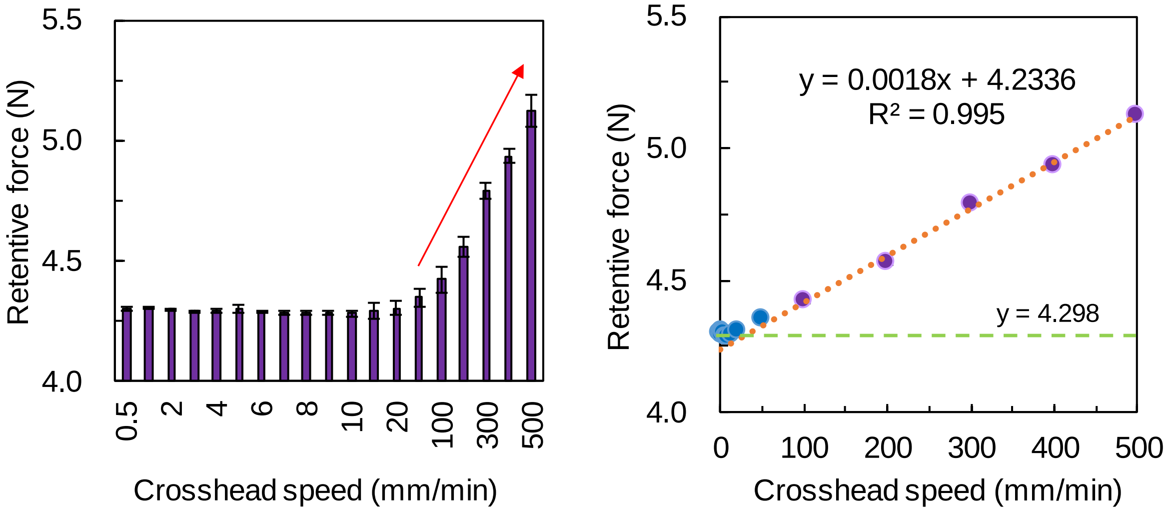


Fig. 3 Measured values of retentive force to crosshead speeds in GIGAUSS magnetic attachment

Retentive force values of neodymium (Nd-Fe-B) magnet at different crosshead speeds are represented in the form of a bar chart in Fig 4a whereas Fig 4b is a scatter diagram. Beyond 50 mm/min, the measured values of retentive force increase with increase in crosshead speed. As shown in Fig. 4b; at crosshead speed of 100 mm/min and more, retentive force and crosshead speed show a strong positive correlation (R^2 = 0.995). Both Sm-Co and GIGAUSS show a strong positive correlation.

In all combinations, the measured retentive force value at crosshead speed of 50 mm/min was higher than the reference value. The difference was not statistically significant. The crosshead speed above which the parameter speed has no influence on retentive force values measured, was determined as the intersection between lines $y = ax + b$ (linear approximate equation) and $y = c$ (c: reference value), as shown in Fig. 4b. The results are shown in Table 1.



a: Bar graph b: Scatter diagram

Fig. 4 Retentive force and crosshead speed in Nd-Fe-B magnets

Table 1 The minimum crosshead speed that influences the retentive force values, derived from the regression analysis.

	Nd-Fe-B	Sm-Co	GIGAUSS
Minimum speed (mm/min)	35.8	42.6	46.8

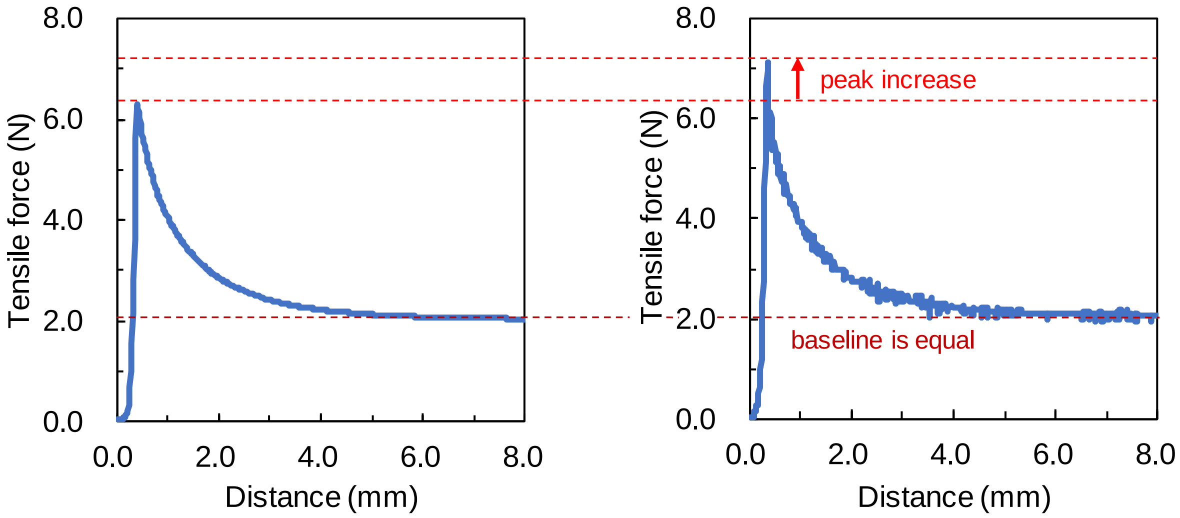
Although retentive forces can be accurately measured at crosshead speed of up to 50 mm/min using a device as specified in the ISO 13017:2020; it is advisable to limit speed to approximately 35 mm/min based on the above results. Ogawa *et al*. reported6) that retentive forces could be accurately measured at crosshead speed of up to 5.0 mm/min. With the development of a high-performance device such as the one specified in ISO 13017; retentive forces can be accurately measured at faster speeds of up to 35 mm/min. Crosshead speed of 2.0 mm/min or less which is specified in ISO 13017:2020 is very slow albeit accurate.

2. Increase in measured values of retentive forces

There was a general increase in retentive forces with increase in crosshead speed. This may be attributed to the influence of friction by the ball bearing slider and acceleration force required to induce movement of the movable part of measuring device up to the set crosshead speed.

2.1 Effect of dynamic friction on measured values of retentive force

Two different types of dynamic friction forces exist: sliding friction and rolling friction. The low friction ball bearing slider used in the measuring device undergoes a rolling type of friction force. The coefficient of rolling friction increases with increase in the rolling speed. In spite of the sharp increase in crosshead speed from 10 to 500 mm/min as shown in the retentive force curves Fig. 5 only the peak force values showed a spike. The baseline force values measured remained steady. These results reveal that the impact of dynamic friction on measured values of retentive force is negligible.



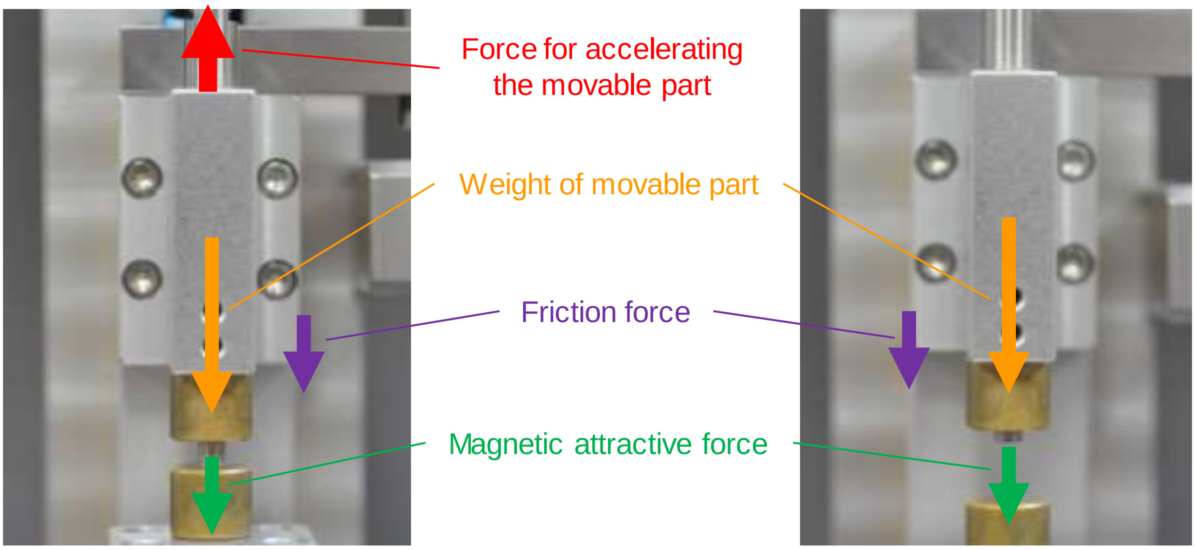
a: 10 mm/min

b: 500 mm/min

Fig. 5 Retentive force curves of Nd-Fe-B

2.2 Effect of acceleration motion force on measured values of retentive force

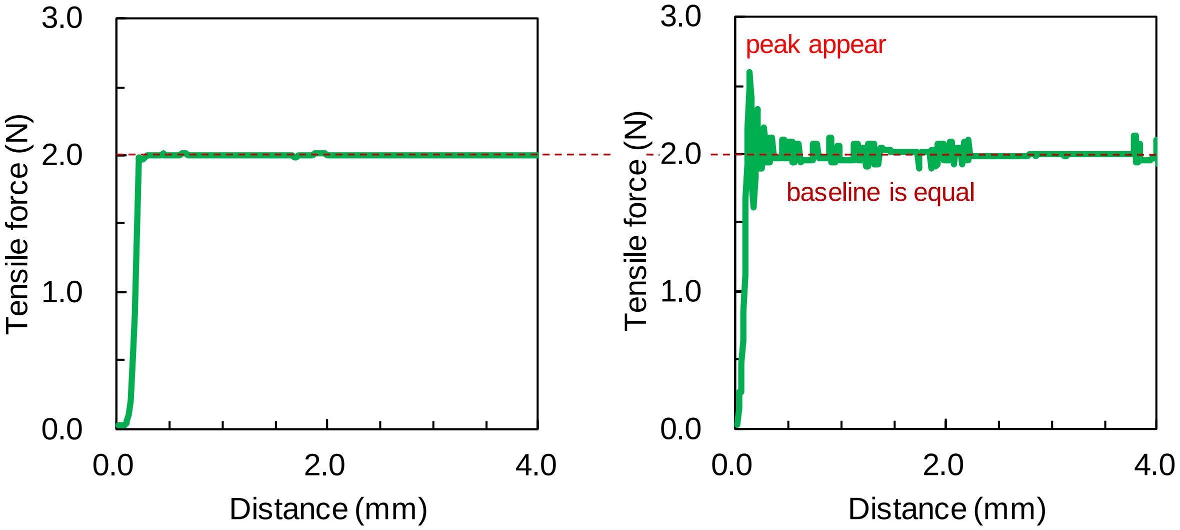
Fig. 6 shows the different forces acting on the movable part of the measuring device during retentive force testing. At the start of the testing shown in Fig. 6a, the movable part of the measuring device requires energy to change from the static state into motion at the set crosshead speed. The force that sets the movable part of device into motion can be derived on the basis of Newton's law of motion equation $F = ma$. The “m” in the equation is equal to the mass of the movable part of device and apparent mass caused by the magnets under attractive force. When the set crosshead speed is attained, the set-up changes from accelerated motion to uniform motion as shown in Fig. 6b. In the absence of force for acceleration, the baseline force values do not change as they are not dependent on crosshead speeds Fig 5. Therefore, the force required to accelerate the movable part is the main contributor towards the pattern of increased measured values of retentive force with increase in crosshead speed.



a: Accelerated motion b: Uniform motion

Fig. 6 Forces acting on movable part of measuring device

To measure the forces acting to the movable part of measuring device; retentive force measurements were done with no magnet or keeper on the lower table. The resultant curves are shown in Fig. 7. At low crosshead speed of 10 mm/min (Fig. 7a), the measured force values showed an initial steep rise then smoothly stagnated after generation of a force sufficient to counter weight of the movable part and friction force. Contrastingly, at high crosshead speeds of 500 mm/min (Fig. 7b), a peak representative of increased force of acceleration exists before stagnation of values measured. Baseline force values for both high and low crosshead speeds were equal. These results further demonstrated that the force of acceleration affected the retentive force values measured. Therefore; crosshead speed has an effect on the retentive force values measured.



a: 10 mm/min b: 500 mm/min

Fig. 7 Curves of net force on movable part of measuring device at low and high cross head speeds

Conclusion

Using the retentive force measuring device specified in ISO 13017:2020, it is possible to measure retentive forces of magnets and magnetic attachments accurately at crosshead speed of 35 mm/min.

Crosshead speeds higher than 50 mm/min, lead to higher measured values than the actual retentive force due to an increase in force necessary to accelerate movable part of device to the set speed.

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