

# Comparing Broom Conditions in Curling: Measurements Using Ice Topography <sup>†</sup>

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**Abstract:** The sport of curling is played on an ice surface with raised ice pebbles and uses curling rocks made of granite. The effect of sweeping is thought to straighten the rock's projected curved path and increase the distance travelled. Recent anecdotes suggest that sweeping from the center of the running surface with the direction of rotation and curl is thought to increase the amount of curl, whereas sweeping against and opposite the curl is thought to decrease the amount of curl. The purpose of this study is to observe the topography of the ice surface while comparing scratch measurements from different broom materials. Nine conditions were replicated: nipped pebble, rock traversing the ice, and seven broom conditions. Replicas of the ice were created with vinyl polysiloxane and observed with an optical microscope. Roughness profiles of the replicas were measured, and broom materials were compared using data from an optical profiler.

**Keywords:** curling broom; curling rock; ice topography; replica; vinyl polysiloxane; sweeping

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## 1. Introduction

Curling is a sport played on ice, where stones or rocks made from granite are slid along the ice with the intention of coming to a stop in the target area (the “house”). The sport is called curling as a rotation is applied to the rock upon release that results in a lateral deviation from the line of delivery the rock travels down the ice. The mechanism of curl or lateral movement has been discussed in the literature; however, experimental and theoretical findings have not consistently agreed.

Among the theories and models are the thin water-layer model [1], snowplow model [2], evaporation-abrasion model [3] and the scratch-guiding theory [4]. The scratch-guiding theorists completed a series of experiments on professionally prepared curling ice which included delivering smooth curling stones on pre-scratched ice using sandpaper, grit P80. The rocks were released with no rotation and then entered the pre-scratched ice, showing a distinct deviation along the scratch direction; however, rocks that were polished did not deviate on the pre-scratched ice. When adding rotation, the polished stone again showed no deviation on ordinary flat ice whereas unpolished stones showed an anticipated sideways motion. This experiment proved strong evidence that the roughness of the stone's running band is crucial to the amount of curl in a game of curling, while also providing evidence that scratches in the ice surface will cause the rock to deviate from the thrown direction.

Once a curling rock is released, with an initial translational and rotational velocity, it is free to slide down the sheet of ice. The only applied factor that can change its path is sweeping—a mechanism by where one or two athletes will move a curling broom back and forth in front of the rock's path, applying both pressure and speed. The goal of sweeping is to decrease the coefficient of friction, which is thought to result in a decrease in curl and an increase in total distance travelled by

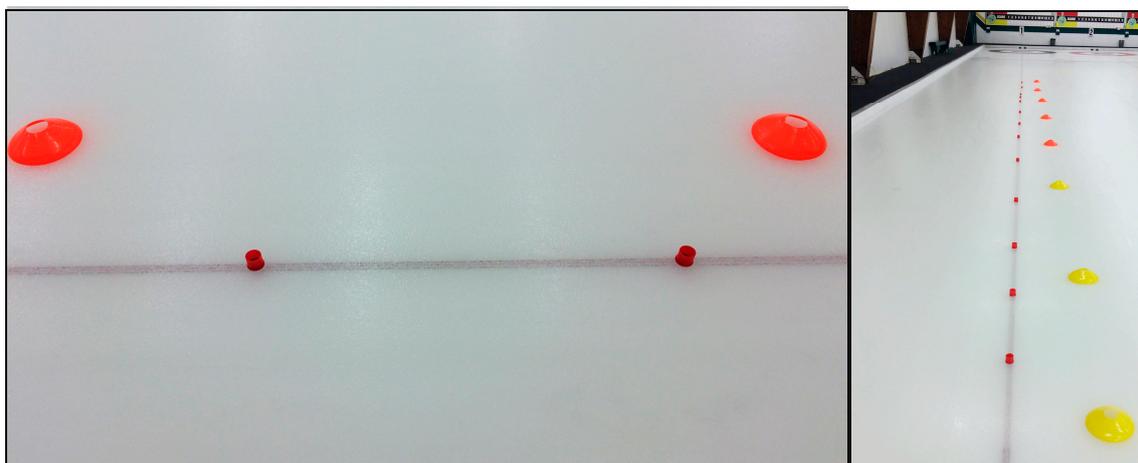
the stone [5]. Recent anecdotal evidence has demonstrated that certain brooms can affect the rock in different ways depending on the direction in which the sweeping occurs. Sweeping from the center of the running surface with the direction of rotation and curl is thought to increase the amount of curl whereas sweeping 'against' or in the opposite direction of the curl is thought to decrease the amount of curl. These anecdotes have sparked some interest in the curling community and provide the motivation for this research.

The goals of this study are first, to prove that these different broom materials are scratching the ice, and secondly, to quantify the depth of the scratches of both the brooms and a curling stone. Based on the anecdotal evidence, it is hypothesized that all the brooms that are restricted from World Curling Federation (WCF) events will show deeper scratches compared to the approved broomhead.

## 2. Materials and Methods

Curling ice preparation included scraping, pebbling and nipping by the standard ice technicians at the respective facilities. Vinyl Polysiloxane (VPS) (Heraeus Flexitime® Medium, Heraeus Kulzer GmbH) was used to create replicas or ice moulds. VPS was cooled in a freezer overnight (ambient temperature  $-11\text{ }^{\circ}\text{C}$ ) and then applied to the ice with a dispensing gun.

A competitive curling athlete (male, 20 years, 113.6 kg, 185 cm) was asked to sweep as hard as possible on the centerline as if it were a draw shot (slow translational velocity), in between two pylons. Following this amount of sweeping, VPS was placed into hollow red cylinders to keep samples of similar size (Figure 1). This process was repeated for each condition, ensuring the impression material was applied to the ice immediately after being swept. The samples were left to set for 2 h.



**Figure 1.** Placement and setting of the ice replicas along the centerline of a single sheet, where one broom was used between two pylons and two replicas were collected with VPS.

Nine total conditions were replicated: normally prepared ice with nipped pebble, one rock, brooms A1, A2, B1, B2, C1, C2 and hair broom (Figure 2). All conditions were performed one after another, with little time between conditions. Additionally, there were no major changes in ice temperature or air temperature during the 2-h set time; therefore, it is assumed that the ice conditions remained constant during the measurement period.

Samples were first investigated through an optical microscope (Nikon Eclipse L150; Nikon Instruments, Melville, NY, USA), where images were saved in tagged image file format (TIFF or .tif) to a PC hard drive. Secondly, samples were scanned using a 3D non-contact optical profiler (S Neox; Sensofar, Barcelona, Spain) to measure the roughness profiles of the samples under the various conditions.

After each sample was leveled and any noise was removed, the profile tool was used to select the area requiring measurement. Once the profile was selected, the distance annotation tool was used to measure both the length (width) and height (depth) of the selected area (Appendix A).



**Figure 2.** Brooms from left to right—A1, A2, B1, B2, C1, C2, and short hair brush. At the time of this experiment, broomhead A1 was the only synthetic material approved for play in all World Curling Federation (WCF) events.

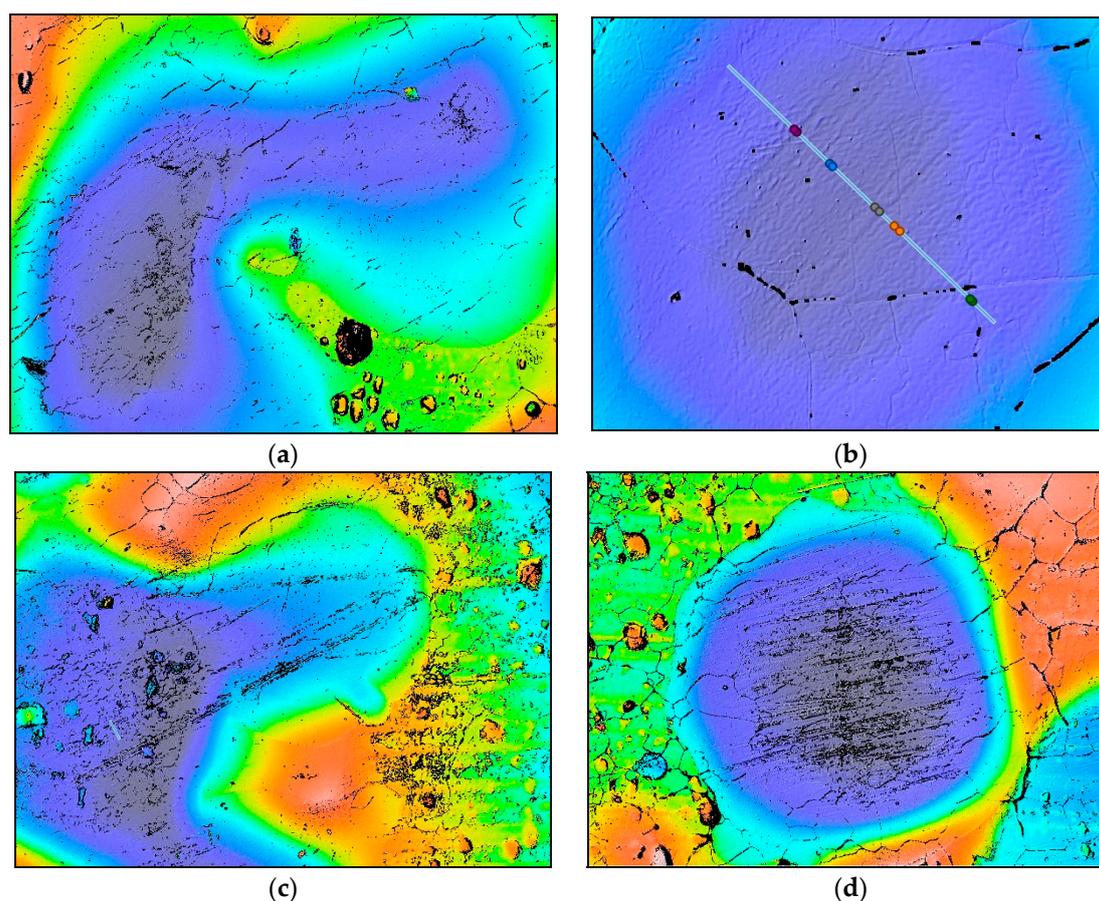
### 3. Results

Images from the profiler software from a select few conditions are displayed in Figure 3 to show the visual differences in the scratches made on the pebble. Some scratches were obvious, as in the case of the hair broom (Figure 3d), and others were not obvious, as in the case with the rock condition (Figure 3a). In the case where the scratches were not as apparent, the profile tool was used to locate the deviations within the sample.

It is clear from Figure 3 that Broom C1 (c) and the hair broom (d) created more obvious scratches on the pebble surface as compared to the rock and broom A1. These scratches are depicted by the dark linear markings in the image(s). It is hard to distinguish any scratches in images (a) and even (b), which are visible only because it is a higher magnification. The range and mean scratch depths are summarized in Table 1.

**Table 1.** Summary of the Range ( $\mu\text{m}$ ) and Mean ( $\mu\text{m}$ ) scratch depths in the ice from the noted conditions.

	Range ( $\mu\text{m}$ )	Mean ( $\mu\text{m}$ )
<b>Nipped Pebble</b>	2.8–8.4	4.64
<b>Rock over NP</b>	1.7–5.7	2.69
<b>Broom A1</b>	1.2–3.2	2.09
<b>Broom B1</b>	1.2–2.8	2.07
<b>Broom A2</b>	1.1–3.3	1.87
<b>Broom B2</b>	1.6–6.3	3.79
<b>Broom C2</b>	3.2–8.3	4.58
<b>Broom C1</b>	4.6–11.4	8.13
<b>Hair</b>	2.6–15.3	7.64



**Figure 3.** Images from SensoScan software showing (a) Nipped pebble with 1 Rock, (b) Broom A1, (c) Broom C1, and (d) Hair broom.

Brooms A1 and A2 were from the same manufacturer, with the same shaft, broom head size and foam density. Brooms C1 and C2 were also made from the same manufacturer using the same shaft, broom head size and foam density. Brooms B1 and B2 used the same shaft, and their head sizes are the same, but their heads are made from different manufacturers and likely have different foam densities, although this was not measured.

#### 4. Discussion

The primary goal of the study was to show that various broom materials, as well as the rocks themselves, are leaving scratches on the pebbled ice surface. The second goal was to quantify those scratches and compare the conditions. Our results showed that all conditions left scratches in the pebble with varying scratch densities and depths.

The previous literature used a similar replica method with the same VPS material; however, an SEM was used to further analyze the samples visually, and no measurements were taken from the samples to quantify the scratches left by, in this case, the curling stone [4]. This study also conducted experiments on pre-scratched ice which lends support to the later-discovered observation of directional sweeping where brooms create scratches in the ice, leading to excessive curl off the curling sheet [6]. A second study used white light interferometry to observe front and rear running surface scratches using a removable slab of ice in a controlled laboratory environment [7]; however, this study shows the scratches only. No measurements of the scratches themselves were evaluated for comparison with the present study.

It is interesting to note that although broomheads A2 and B1 are both restricted for WCF events, their scratch measurements were similar to that of the approved broomhead (A1) in both range and mean. This approved broomhead material (Nylon Oxford 420D) was chosen by a group of athletes

after testing multiple materials during the WCF sweeping summit where trajectories were observed and it was decided that this material did not exhibit any signs of directional sweeping [6].

The first limitation to this study was the limited number of pebble samples that were taken and compared. Future research should evaluate multiple pebble samples (not just multiple scratches per pebble). A second limitation of this study is the inherent variability in the measurements since we did not take replicas of the exact same pebble for each condition. The VPS material takes a long time to set on the ice surface ( $-5\text{ }^{\circ}\text{C}$ ), and without marking the exact location which would possibly damage the playing surface, it is not possible to measure the same location with this technique. There is also some variability, since the pebbles are all slightly different heights and diameters which could possibly affect the depth of the scratches. While other experiments may be able to observe the same location for all tests, this study's strength lies in its ability to quantify measurements beyond visual observation.

## 5. Conclusions

This study provides measurements of what is happening to the ice surface, in a quantifiable manner. The curling community had speculations about scratches created from rocks and brooms, but while there is literature demonstrating the existence of scratches, none have quantified the depth of these scratches to date. It was found that synthetic brooms C1 and the hair broom created the largest mean scratch depths, as well as the widest range of depths, over the samples collected. Scratches were still apparent with the broomhead approved for WCF competition, but measured much smaller, at approximately one quarter of the depth.

These findings contribute to the notion that directional sweeping is the result of scratching the ice in a specific direction as it travels down the ice. While the results of this study do not directly support any one theory behind the mechanism of deflection in a curling stone, the values from the rock scratches measured can be used to determine the impact and shear forces on the pebble surfaces, which will help in the development of an accurate model in future research.

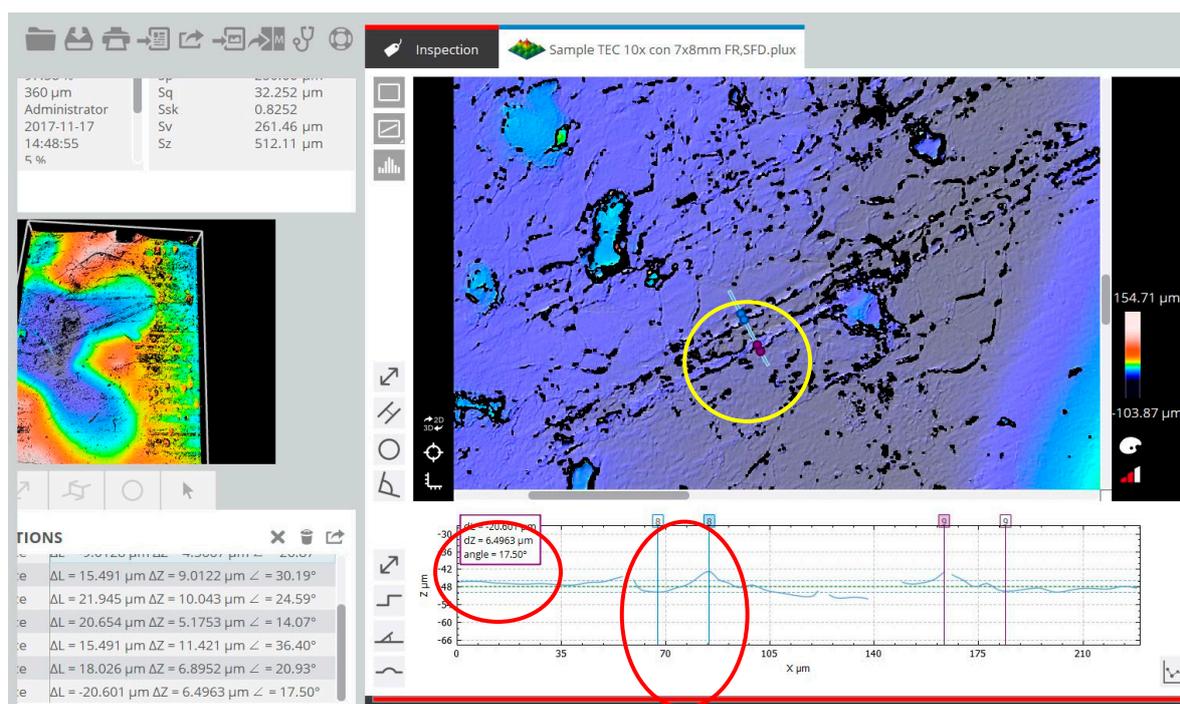
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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

The Form Removal operator was used for samples that need to be leveled due to a tilt (linear form). Eliminates any tilt during the scan. SMART *Despiking* filter was used to delete noise peaks from the surface. To distinguish which are good or noise points, the software calculates the average and the standard deviation in an area of  $5 \times 5$  pixels for each 3D measurement pixel. Then, if the values are too different, these points are rejected and classified as lost pixels.

To take a measurement, use the PROFILE measurement tool to select the area you want to measure (Figure A1) (circled in yellow). Then, use the distance annotation tool to choose what you want to measure—both length (delta L) and height (delta Z) (circled in red).



**Figure A1.** Screenshot from SensoScan software illustrating the profile measurement tool over the selected scratches (top), and the distance annotation tool measuring the selected profile (bottom).

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