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Research Article

Correlations between curling stone frictions and tribology's Stribeck curve: concepts to consider

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Abstract

The glides of curling stones to the button on curling-sheet ice are composed of three segments: (*i*) an initial high-speed travel characterized by mild decelerations (and minor curls); (*ii*) a slower-speed segment with visibly greater rates of deceleration (and curl); and (*iii*) an abrupt end-of-travel. It is proposed here that these three travel segments correlate with the three well-known frictional regimes of tribology's Stribeck curve: (*i*) a hydrodynamic (wet) frictional regime in which, at high speeds, the generation of frictional heat from shearing stress within a lubricating water film is sufficient to melt ice and fully isolate the rock's running-band from the ice surface, i.e., from mutually abrasive contact; (*ii*) a mixed frictional regime where, with ever-more severe friction and ever-stronger deceleration and thus ever-lower speeds, the generation of frictional heat is progressively less and the lubricating water film becomes ever-thinner, allowing rock and ice asperities to cut ever-more abrasively into their opposing surfaces; and (*iii*) a totally dry, highly abrasive frictional regime in which, at very low speeds, lubrication ends because of the lack of sufficient frictional heat to maintain a water film and thus the rock's advance comes to an abrupt end.

Key words: curling, frictions, dry-mixed-wet (hydrodynamic), Stribeck curve, segmented travel

Introduction

Launched on well-groomed ice at a draw-to-the-button speed of about 2–3 m/s[1], a curling stone typically slides for about 25 s over approximately 28 m (Fig. 1). Even with the momentum of a rock's 20 kg weight, the overall friction between a rock and ice must be very low for the rock to slide so long and over such a distance. Furthermore, an observer may note that the slide is visibly divisible into three travel segments, each undoubtedly resulting from different frictions. The intent of this communication is to describe and explain the character, origins, and consequences of these frictions and decelerations over a rock's 28 m draw. These constraints may prove useful in future interpretations, such as in explanations for the curious curls of curling stones on curling-sheet ice.

Curlers assume, with ample reason (see Appendix A), that a sliding curling stone is lubricated by a thin film of melted ice (i.e., water), which in turn results from frictions and frictional heat generated by the sliding of a heavy rock over ice on its narrow running band. Furthermore, it is widely appreciated that running bands are carefully textured[2] such that hard granite asperities[3] may plow across the flat tops of nipped ice pebbles and result in physically abrasive solid-on-solid contacts. The resulting friction and frictional heat, and therefore the amount of water in the lubricating water film, is presumably proportional to the rock's speed.

Tribologists[4] might suggest that the frictions between curling stones and curling-sheet ice could be more complex. In their endless attempts to reduce or eliminate wear between sliding solid surfaces in industrial contexts, they have noted, for example, that, even at very low speeds of travel of one solid over the other, select lubricants are capable of physically "lifting" one solid above direct physical contact with the opposing solid (as with railway-car axles rotating within their journal bearings). Such findings could have important implications with respect to curling

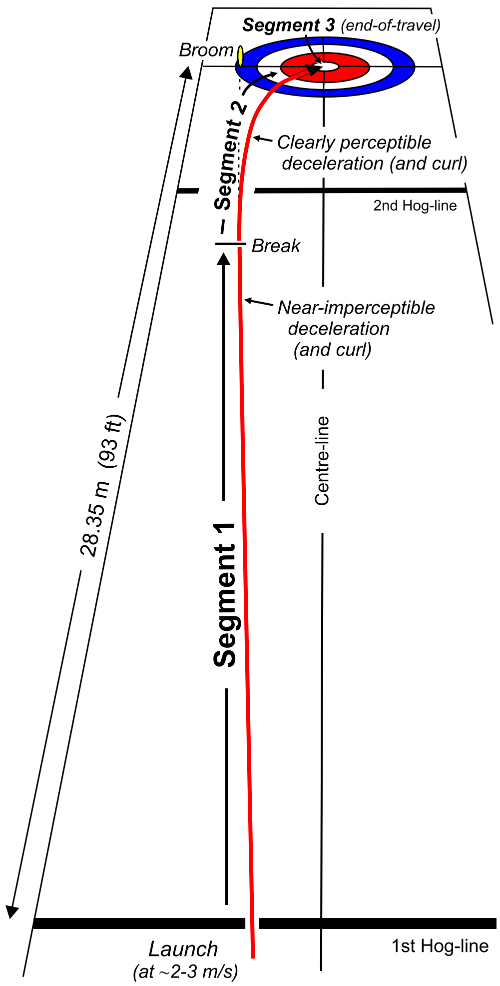
[1] The only delivery considered in this communication.

[2] In the manufacture of curling stones, the entire stone is initially cut and polished to have a gleaming, gravestone-like appearance. The running band alone is then textured (roughened, sandpapered) to provide the curl desired in curling stones (note: rocks having polished running bands do not curl [2]. Texturing is typically done by deliberately sliding the rock on its running band over fine-grained sandpaper (e.g., a few controlled short strokes over P80-120 silicon-carbide sandpaper). See https://www.youtube.com/watch?v=5eZy5RULzKE; https://www.facebook.com/ovcacurling/videos/1706457212765227/.

[3] The dominant minerals of granite (feldspars and quartz) have Mohs hardnesses between 6 and 7, whereas mildly frozen ice has a much softer hardness of 1.5–2. Consequently, the running bands of rocks require occasional re-texturing, whereas ice sheets require refurbishing after every game.

[4] Tribology is the science and technology of friction, lubrication and wear.

Fig. 1. The segmented travel of a curling stone over a draw to the button. Segment 1 is characterized by a fast, easy glide with minor deceleration (and curl) attributed to wet friction; segment 2 is characterized by ever-stronger decelerations (and ever-increasing curls) attributed to mixed friction; and segment 3 consists of an abrupt end-of-travel attributed to dry friction. See text for further descriptions and explanations.



stones sliding over pebbled-and-nipped curling-sheet ice, as discussed below. Whereas curlers may routinely assume that curling stones roar on ice because of uninterrupted abrasive contacts between the rock and ice, it may be asked whether the lubricating water film generated by frictional heat between the rock and ice could be sufficiently thick that the rock is fully lifted above abrasive contact with the ice surface, especially over high-speed portions of its travel. The possible types of friction generating frictional heat at varying speeds should be important in understanding the varying behaviors (e.g., variable decelerations) of curling stones on ice. Such crucial concepts are addressed at length below.

Observations and interpretations

Varying travel behaviors for curling stones on ice

From endless on-ice observations, it is well known that the lubricated glide of a curling stone to the button is not a simple slide: a rock curls and decelerates at variable rates[5] over distinct segments of its travel. Launched at a modestly high speed (e.g., 2–3 m/s; Fig. 1) and with a rotational speed of about 2–3 full turns over its full travel, the rock initially decelerates (and curls) at low rates over an initial travel distance that varies from about one-half to three-quarters of the total draw to the button (known here as travel segment 1)[6]. The rock then adopts visibly ever-stronger rates of deceleration (and curl[7]) over most of the remaining slide to the button (travel segment 2). The typically visible change in sliding behaviors between segments 1 and 2 is generally known as “the break” (also the “bend” or “snap”; comparable to “the hook” in ten-pin bowling). Finally, the rock’s travel ends abruptly (travel segment 3), normally over a centimeter or less [3, 4]; the change in sliding behaviors between travel segments 2 and 3, if decernable, could be called the “2nd break”. This communication focuses on the natures and origins of these three travel segments and on the frictions responsible for the distinct sliding behaviors over each travel segment.

Essential tribological concepts

According to well-established tribological principles, a sliding curling stone should encounter *two types of friction* (dry and wet) and *three frictional regimes* (dry, mixed, and wet)[8] (Fig. 2). Dry friction may be considered “adhesion shear deformation” [3], which, on curling-sheet ice, may be envisaged as hard granitic asperities on the rock’s running band cutting abrasively into and across soft, nipped ice pebbles beneath[9] (Fig. 3). Dry friction alone, characteristic of the friction over end-of-travel segment 3, occurs only at very low speeds, at which the generation of frictional heat is insufficient to melt appreciable amounts of ice; consequently, running-band as-

[5] The curler’s endless challenge is to understand and anticipate these rates, based on experience and science.

[6] In this communication, the term “high speed” is limited to the launch speed necessary for a draw to the button and to all travel speeds as far as “the first break” (i.e., all speeds experienced over travel segment 1, as identified in Fig. 1). Higher possible speeds on ice, such as those associated with peels and take-outs, are excluded. With progressive deceleration, “intermediate to low speeds” apply to segment 2, and “end-of-travel speeds” apply to segment 3.

[7] Unlike most recent communications dealing with curling stones, this text does not attempt to explain the curls of rocks on ice. However, it is obvious from the behavior of curling stones on ice that the strengths of curls correlate closely with rates of deceleration. Thus, better understandings of decelerating frictions should lead to increased understandings of curls (a concept currently under consideration). Curls are not discussed further in the present paper.

[8] Dry, abrasive friction is also known more formally as boundary friction, whereas wet, shearing-stress friction within a lubricant

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