STATIC AND DYNAMIC CHARACTERISTICS OF COMPOSITE ONE-PIECE HOCKEY STICKS

Etienne Simard, Eric Roy, Geneviève Martin, Hugo Cantin, and René Therrien*
***Sherbrooke University, Sherbrooke, Québec, Canada.**

The purpose of this study was to evaluate the differences in static and dynamic characteristics of one-piece composite hockey sticks of different brands and models. Earlier studies had only evaluated two-pieces sticks of different materials. Even if some static results present many similarities with those disclosed by earlier researchers, torsion tests have demonstrated one-piece composite sticks to be much more torsion resistant than two-pieces and wooden sticks. Furthermore, dynamic evaluations have disclosed very interesting puck-blade interactions, including multiple puck-blade impacts in actual slap shot situations.

KEY WORDS: ice hockey, stick, equipment evaluation, composite.

INTRODUCTION: Today, hockey sticks made with composite materials are very popular. These composite materials, like graphite, carbon and kevlar, are used to produce lighter, more durable and supposedly more efficient sticks. Unfortunately, very few studies have been published concerning the characteristics of this important piece of hockey equipment. Robichaud (2002) suggested that in order to increase shooting power a player applies a force on the hand placed farthest on the stick, while the latter is in contact with the ice, in order to flex it and thus store energy. Then, this process allows for a whipping action of the blade to take place, as soon as ice friction is decreased, just before puck release in the direction of the target. This tentative explanation gives information on the shooting technique but does not indicate what type of stick is more appropriate to produce an accurate and powerful shot. Obviously, it depends on the characteristics of the stick in relationship with the individual characteristics of the player who uses it, as well as on the technique used. Marino (1998) indicated that the variables contributing to how a hockey stick feels and performs included: weight, center of mass location, shaft flex, resistance to twisting and breaking force. Technique and environmental conditions are other factors that can contribute to favour one type of stick over another.

Pearsall & al. (1999) examined the influence of shaft stiffness on puck velocity, as well as the response characteristics of two-pieces composite ice hockey sticks during a slap shot. They selected sticks of four different stiffness levels and analysed the mechanics of the slap shot. Ground reaction forces were calculated from force plate data and stick deformation was obtained from a high-speed film. They also used a radar gun to evaluate puck velocity. Their results indicated that sticks with lower stiffness produced the highest puck velocities, the biggest amount of shaft deflection, the longest time to peak deflection and the lowest peak Z forces. However, the time intervals to obtain the peak forces in the Y and Z directions were similar for shafts of all different levels of stiffness. They also found that the puck velocity was influenced by the interaction between the subjects and stick stiffness. According to these researchers, variability in performance measures across subjects was greater than the variability across stiffness.

After comparing aluminium, wood and composite two-piece hockey sticks, Marino (1998) found some advantages to use composite hockey sticks. According to him, composite sticks are lighter than those made with other materials; they are similar to others sticks in centre of mass location and flex strength and close to the twist characteristics of the wooden sticks. The same conclusion was proposed in the study by Robichaud (2002); moreover, the latter suggested to pursue more investigations on one-piece composite sticks because no information was available on this newly developed equipment. In the present study, an attempt is made to learn more about the one-piece hockey sticks made with composite materials. The purpose of this study was to evaluate the differences in static and dynamic properties of one-piece composite hockey sticks.

METHOD: Four one-piece composite hockey sticks of different makes and models were evaluated and compared to one two-pieces wooden stick, used as control. All sticks had comparable shape characteristics. Static tests were performed first. Then, the upper part of the shafts were cut to uniform length in order to adapt to the shooter's technique, for the dynamic tests.

Static evaluation of the sticks included measurement of the following parameters: weight (W), relative center of mass location (RCML), shaft linear flexibility (SLF), blade linear flexibility (BLF), shaft torsion (ST) and blade torsion (BT). Evaluations were performed in the same manner as described by Marino (1998) and Robichaud (2002).

Weight (W) was measured with an electronic balance, with an accuracy of +- 0,001g. Relative center of mass location (RCML) was calculated as the ratio between the distance from the upper part of the shaft to the center of mass (CM) and the total length of the stick.

Shaft linear flexibility (SLF) was performed in the same manner as SF, except that weights (15, 20 and 25 kg) were placed at 80 % of the shaft length and deflections measured in this latter location.

In order to evaluate blade linear flexibility (BLF), the heel of the blade was fixed in a vise while the shaft was held flat on a table. Then, free weights (10, 15, 20 and 25 kg) were suspended at the end of the blade and deflections (in cm) were measured.

Measurement of the shaft torsion (ST) required the building of a jig in the shape of a long box with a hole at both ends. The stick was inserted through the hole (no friction) and the end of the shaft was fixed in a vise. Weights (5, 10, 15 and 20 kg) suspended to a lever perpendicular to the end of the blade produced shaft torsions measured with a goniometer positioned on the box at the lower end of the shaft (15 cm above the heel of the stick).

The blade torsion (BT) test was performed with the heel of the blade clamped in a vise, while free weights (4, 6 and 8 kg) applied a torsion force to the end of the blade; the amount of torsion of the end of the bade was also measured with a goniometer.

Dynamic evaluation of hockey sticks performances included measurement of the two following parameters, puck-blade interactions (PBI) and shaft deflection angle (SDA) while a semi-professional hockey player actually performed slap shots, in a laboratory situation. A polyethylene surface has been taped to the floor and WD-40 lubricant has been sprayed on the surface, to simulate an ice rink situation

In order to evaluate puck-blade interactions (PBI) a wide piece of black tape was placed on the side of the blade hitting the puck, while white chalk was applied all around the puck. With this setup, each contact of the puck left a precise white mark on the black tape. The number of marks was recorded and the distance between each was measured. Tape was replaced and new chalk applied before each shot. Ten (10) shots were performed with each stick.

Shaft deflection angle (SDA) during slap shot was evaluated from high speed video sequences, using a method similar to that used by Pearsall & al. (1999). Five (5) trials were filmed for each stick.

RESULTS: Tables 1 and 2 summarize both static and dynamic measurements.

Table 1 Static Test Results.

Stick		One-piece composite sticks **Mean**	(range)	Two-piece Wooden stick
Weight (W)		**473,75 g**	(442-494 g)	640,00 g
Relative Centre of Mass Location (RCML)		**57,35%**	(56,06–58,42%)	52,78%
Shaft Linear Flexibility (SLF)	(15 kg)	**1,25** cm	(0,6-1,7 cm)	2,40 cm
	(20 kg)	**1,78** cm	(1,0-2,3 cm)	3,20 cm
	(25 kg)	**2,33** cm	(1,3-3,0 cm)	4,20 cm
Blade Linear Flexibility (BLF)	(10 kg)	**1,68** cm	(1,0-2,3 cm)	2,70 cm
	(15 kg)	**2,75** cm	(1,7-3,4 cm)	4,60 cm
	(20 kg)	**3,88** cm	(2,6-5,0 cm)	6,10 cm
	(25 kg)	**5,35** cm	(4,5-6,1 cm)	8,10 cm
Shaft Torsion (ST)	(5 kg)	**0,46°**	(0,3°-0,5°)	5,00°
	(10 kg)	**1,00°**	(1,0°-1,0°)	9,50°
	(15 kg)	**1,75°**	(1,5°-2,0°)	14,00°
	(20 kg)	**2,88°**	(2,5°-3,5°)	19,00°
Blade Torsion (BT)	(4 kg)	**1,88 °**	(0,5°-3,0°)	3,50°
	(6 kg)	**2,50°**	(1,0°-4,0°)	4,50°
	(8 kg)	**3,50 °**	(1,5°-5,0°)	5,50°

Table 2 Dynamic Test Results.

Stick	Puck-Blade Interaction: Average distance travelled by the puck (mm)	Puck-Blade Interaction: Number of rebounds	Shaft Deflection Angle: Average deflection angle
Composite 1	199	3,9	13,5°
Composite 2	230	3,8	15,6°
Composite 3	200	3,5	11,0°
Composite 4	173	4,1	11,5°
Wooden	211	3,6	16,0°

DISCUSSION: Static test results show that one-piece composite sticks are not only lighter (25 %) than the wooden reference stick but also that their CM is located approximately 5 % lower, contributing to the light feeling reported by professional players. As expected with composite materials, both shaft (45 %) and blade (37 %) linear flexibility are much lower in one-piece composite sticks than in the reference wooden stick. These results offer many similarities with those reported by Marino (1998) and Robichaud (2002). However, the largest differences were obtained for shaft torsion, which was close to 10 times smaller in one-piece composite sticks. This phenomenon added to blade torsion which was almost twice less important in the composite stick may be the most contributing factors to the quickness feeling reported by professional players using one-piece composite sticks. However, these ultra-rigid properties do not necessarily translate into more powerful shots. As a matter of fact, the highest velocities (160 to 168 km per hour) recorded in NHL hardest shot contests over the past ten years were performed with many different types of sticks, including wooden, two-pieces (aluminium or composite shaft with wooden blade), and more lately, one-piece composite sticks. However the single highest velocity (168 km per hour) was performed by a player using a two-piece wooden stick. This raises questions about the need for ultra-rigid sticks. Analysis of dynamic tests results did not disclose large differences between the two types of sticks, except for blade deflection angle which was 19 % lower (as expected) in composite sticks.

However, dynamic testing allowed for the identification of a very interesting phenomenon taking place at the puck contact: actually sequences of either three or four puck-blade contacts took place in each individual slap shot performance, as evidenced by the white marks left on the black tape strips. Moreover, these marks showed that after the initial impact, the puck displaced about 20 cm along the blade towards its tip, during this multiple rebounds period, before leaving the blade towards the target. The many factors involved in puck-blade interactions emphasize the important role of equipment characteristics in order to allow for accurate and powerful shots. Moreover, the use stiffer sticks raise new questions about their capacity to allow for as precise stick handling and pass reception as with more traditional and more yielding two-piece wooden sticks.

CONCLUSION: Static and dynamic tests performed on one-piece composite hockey sticks, within the scope of the present study, disclosed both shaft and blade torsion resistance were the main differences between these sticks and a traditional wooden stick. These evaluations also pointed out multiple puck-blade impacts to occur during slap shot, thus adding additional difficulty to the already delicate task of performing powerful and accurate shots. However, present day manufacturing techniques with composite materials allow for much more consistent characteristics reproducibility than with wooden material.

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