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BLADE SHARPNESS AND ITS EFFECT ON THE TESTING OF BODY ARMOURS

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Summary

Factors such as edge sharpness and tip sharpness have been identified by *Horsfall,*[1] as key variables in the testing of stab and slash resistant armours. This paper evaluates the influence of blade sharpness on the mechanics of penetration and its relationship with a variety of materials used for body armour systems. The differences in performance between blunt and sharp blades are compared by dynamic tests using an instrumented drop tower, measuring peak loads and energy to penetration. Variance in the initial impact forces required to penetrate body armour between blunt and sharp blades is shown. However, the total energy to penetration for both sharp and blunt knives was found to be similar for a specific body armour system. Dynamic tests were also used to evaluate the effect of wear on blade performance by the comparison of the initial loads for puncture and depth of penetration on aramid and metallic armour systems. The effect of sharpness on the reproducibility of test results is also investigated and discussed. Various test methods are described for the measurement of sharpness for both stab and slash and compared. The recent development of a new non-destructive proof test method to measure tip and edge sharpness is also described.

Effects of the sharpness of blade tips

An instrumented drop tower was used for a number of impact tests against a 5.5mm thick aramid-thermoplastic target to measure the variance in initial impact forces and energy to penetration of a number of double sided ‘commando style’ blades. The blades were tested in their ‘as received’ sharp condition and then again after deliberate blunting. The difference between the sharp and blunted blade tips before testing is illustrated in figure 1.

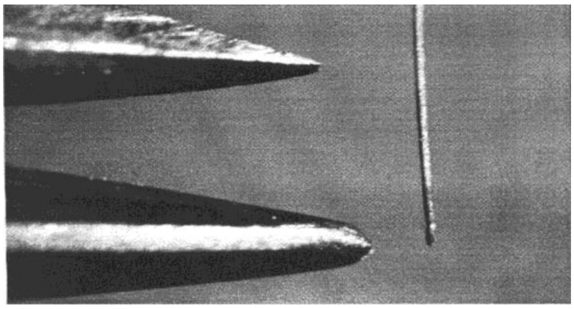

Figure 1. Macro photograph of sharp (top) and blunted (bottom) knife tips including a 50μm diameter wire for scale.

Impact forces were measured directly using a force transducer mounted behind the knife blade and the energy for penetration was measured by calculating the area under the force displacement curve. The targets were backed by Roma plastilina® No. 1 and the penetrations measured by the method described by Watson *et al*[2]. For input energies of 44 Joules the measured depth of penetration from the knives was found to be similar regardless of blade condition. Figure 2 shows the force vs. displacement plots for a test each with a blunt and a sharp knife. It can be seen that the sharp knife produces a lower initial peak force, but the force resisting penetration actually climbs above that for a blunt knife after perforation has occurred.

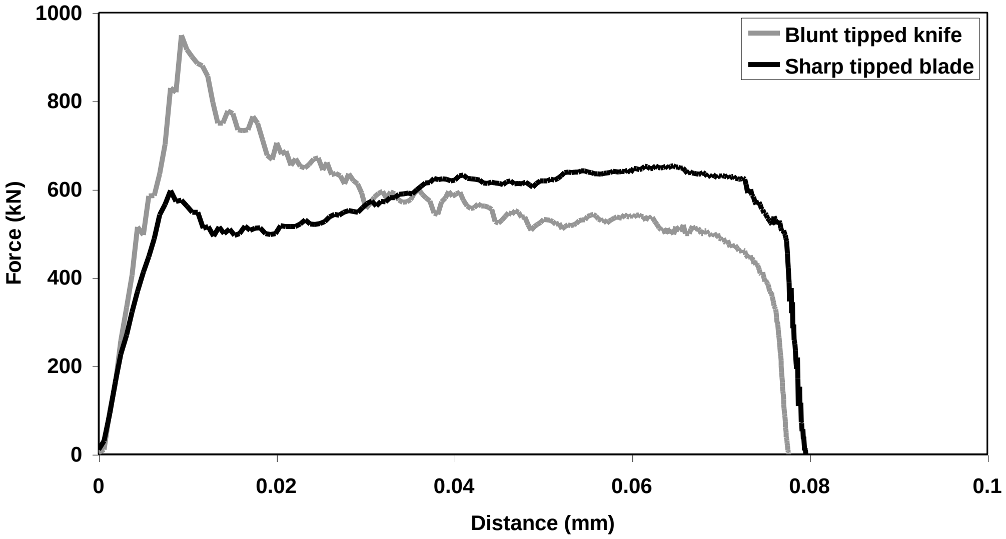

Figure 2. The force vs. displacement plots for blunt and sharp knives on 5.5mm thickness aramid-thermoplastic composite.

Blade sharpness and wear effects

Further tests were also conducted in order to assess blade degradation. The procedure was to perform 30J drops with a double-edged knife on aramid-thermoplastic composite and 7075-T6 Aluminium alloy targets, the aluminium was in the peak-aged condition for maximum strength. As before targets were backed by Roma plastolina® and penetrations measured by the method described by Watson *et al*[2]. Test drops were carried out with new blades and repeated after the blades had been used for a number of tests on various other targets. The data are summarised in table 1.

Table 1. The effect of wear on blade performance.

Target	Knife Condition	Initial peak load (N)	Penetration (mm)
Aramid-thermoplastic composite	New blade	476	50
	Same blade after 6 drops on 7075-T6	550	52
	New blade	492	48
	Same blade as above after 7 drops on titanium	547	47
7075-T6 Aluminium alloy	Nearly new blade (1 drop on Aeroflex®)	561	50
	As above after 9 drops on titanium	579	47

After several tests with a new blade against the aluminium target, to simulate wear, initial loads for perforation on the aramid target showed an increase of up to 20%. The effect of wear on levels of penetration was not significant with both increases and decreases being observed. The effect of repeated use of test blades was seen to be relatively small, and was comparable to the difference between individual blades of the same type.

The penetration of armour by a knife progresses through number of stages with different parameters controlling each stage. Upon initial contact with the armour the force resisting the knife increases rapidly up to a point where perforation occurs. The magnitude of the force at perforation is strongly dependent upon the tip sharpness of the test blade. Perforation occurs because the impact energy is dissipated over a very small area so that the armour is defeated locally before the impact can be absorbed in global processes such as bending.

After perforation the resistive load of the armour generally decreases and the blade slides through the opening. The resistive load is a function of the force required to expand the hole and the frictional forces between the blade and the armour. The magnitude of the resistive loads after perforation is determined by the blade shape, surface finish and to some extent the target damage caused during perforation. Sharp cutting edges significantly decrease the load required to expand the hole particularly in the case of the textile targets. Minimising blade cross section also reduces penetration forces although this has to be balanced against buckling strength of the blade. The importance of blade sharpness in the defeat of armour systems has lead to the necessity for accurate measurement of the sharpness of blades used for standard tests, and various methods for measuring the sharpness of blades have been developed.

Tip sharpness measurement – The Mitutoyo ATK1000 Rockwell hardness test adapted for a sharpness test

A standard Mitutoyo ATK1000 Rockwell test machine can be used to perform a Superficial Rockwell test for testing coatings and thin samples. In this mode an initial load of 3kg and a major load of 15-45 kg is used. For knife tip sharpness measurement the Rockwell machine was operated in the superficial mode and was modified to produce a major load of 5kg, the Rockwell test procedure and measuring system was retained. This was to provide the greatest sensitivity and the least amount of damage to the knife tip. For the measurement of knife tip sharpness a knife was substituted for the indenter. To minimise the stresses placed on the tip during the sharpness test, a very soft substrate is used, together with the minimum possible loads. The test sample is 99.997% purity Aluminium approximately 5mm in thickness, ground and polished to produce a smooth parallel and un-deformed surface.

In principle, a depth-measuring test should be sensitive to the shape of the indenter. For a given sample, any indenter will sink in until its projected area is sufficient to support the applied load given the flow stress of the sample. The Standard Rockwell C indenter is a diamond cone with an included angle of 120º and a tip radius of 0.20mm. Typical test knives have tip angles of 5º-10º and tip radii of less than 0.05mm. Even with lower applied loads the indentation levels produced are substantially greater than would be achieved during a standard hardness test. It can be seen from figure 3 that for a sharp indenter and a soft sample the indentation will exceed the standard reference line depth. Consequently the hardness value expressed in the equation below will be negative. There is usually a maximum depth to which the test machine can measure, in the case of the Mitutoyo ATK1000 this corresponds to an indicated hardness of –160. Therefore the sharpness of the knife is expressed in terms of a nominal Rockwell hardness value.

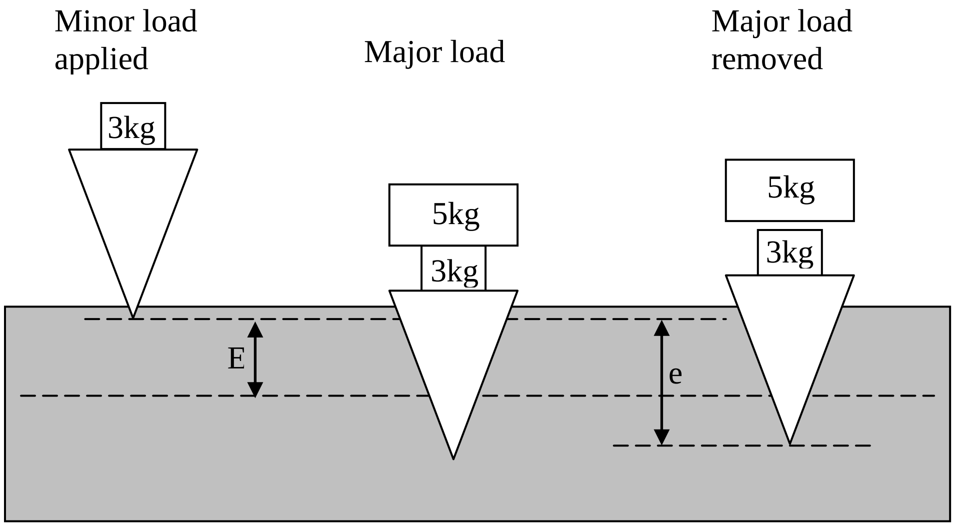

Figure 3. A diagrammatic illustration of the Rockwell hardness test as adapted for knife tip sharpness testing.

These values can also be expressed in terms of indentation depth produced by the major load application, table 2.

$$D = (HRC - 100) \times {}^{-}0.002$$

Where:
D indentation depth in millimetres
HRC indicated hardness value on Rockwell C scale

Table 2. Indentation depth as a function of indicated Rockwell C value

Sharpness (Nominal HRC)	Indentation depth (mm)	Sharpness (Nominal HRC)	Indentation depth (mm)
-160	0.52	-70	0.34
-150	0.50	-60	0.32
-140	0.48	-50	0.30
-130	0.46	-40	0.28
-120	0.44	-30	0.26
-110	0.42	-20	0.24
-100	0.40	-10	0.22
-90	0.38	0	0.20

Sharpness trials on engineered blades

Since the introduction of the PSDB Stab Resistance Standard (1999) all blades have been tested using the above method. Test results for 2914 P1 blades, figure 4, shows that 98.6% have indicated sharpness values that lie in the range –110 to –150. On closer inspection of the 1.4% of blades falling below the –110 level (i.e. less negative, more blunt) have generally shown manufacturing defects.

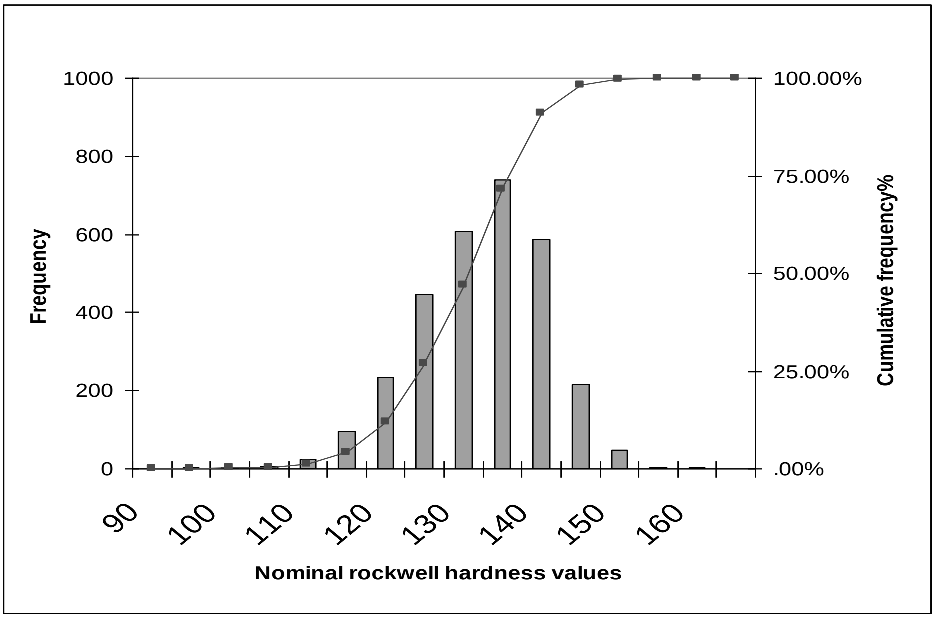

Figure 4. Nominal Rockwell hardness readings from 2914 tests on PSDB P1blades

Development of an edge sharpness test.

For body armour systems incorporating metallic layers, their resistance to puncture by the sharp knife tip is the primary protection mechanism. Edge sharpness may also be a significant factor when evaluating the performance of fabric only body armour systems. These systems resist penetration by allowing the blade tip to penetrate some layers and relying on the remaining layers resisting cutting by the edges of the blade.

Further research into slashing attack using a Stanley® blade found that the edge of the blade is also in contact with the armour during an attack[4] and the relative performance of sample armours was dependent on blade geometry. Therefore, for this type of attack edge sharpness may also be a contributory factor to material failure. A slash resistance test[5] has been devised based on the drop tube assembly for stab resistance tests using a modified sabot and target. The edge of the knife blade for this test is currently unspecified. The development of the PSDB Stab resistance standard[1] showed that the tip of a blade is undamaged when pressed into a 99.9% pure aluminium block. Adapting this method to measure the edge sharpness of a Stanley® blade using the same grade of aluminium was investigated.

Modification of the Rockwell® test machine for edge sharpness measurement

The grade of aluminium used for the PSDB test is also available as ½” (12.5mm) diameter round bar. As a test block the profile of the round bar would allow the load to be applied to the edge of the blade gradually and the applied loads necessary would not exceed the maximum load for the Rockwell® machine. A channelled support block for the round bar and two holders allowing a Stanley® blade to be clamped firmly in two positions were manufactured. One holder had a slot channelled at 0 degrees so that the edge of the blade could be pressed into the round bar. Another clamp had a slot channelled at 24 degrees, which allowed the tips of the blades to be tested, figure 5.

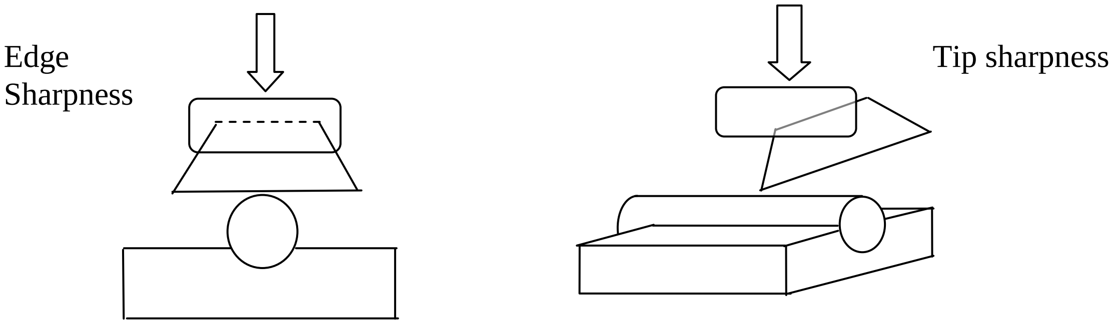

Figure 5. Diagrams of the arrangement of support block and Stanley® blades for the Rockwell® testing machine

Stanley® blades were mounted on the machine so that the edge of a blade was at right angles to the aluminium bar and a modified Rockwell® test[1] was carried out. A pre-load of 3Kg (minor load) was applied to the blade then the major load of 5Kg was applied. The readings from the Rockwell® tester were compared with readings from a different test method and will be discussed later. Ten sharp blades and thirty Stanley® blades that had been previously blunted at the Cutlery and Allied Technology Research Association (CATRA), were tested in the modified Rockwell® machine. This was to determine if damage occurred when the edge or tip of a blade was pressed into the aluminium bar. Damage to the edge and tip of each blade was assessed, by photographing the blades before and after each test. The edges of the blades showed no visible damage when they were pressed into the aluminium bar.

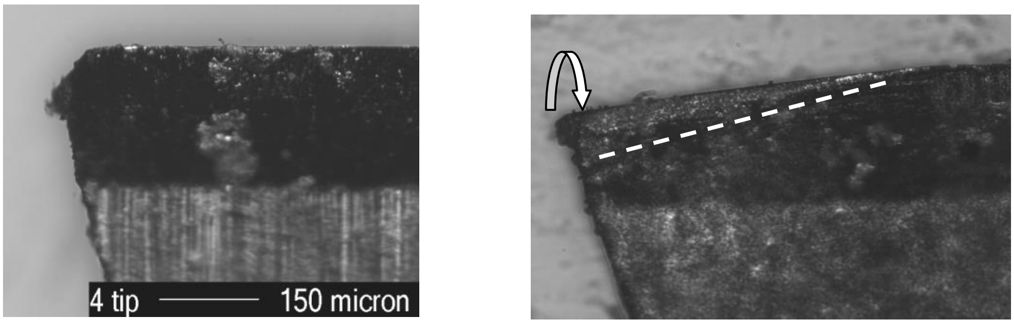

Figure 6. Tip of a Stanley® blade before (left) and after (right) being pressed into a pure aluminium bar (same magnification)

Damage to the tips of some blades was visible with some blades rolling over at the tip, figure 6. As the Stanley® blades are clamped at 24 degrees for the tip test, any small misalignment may cause a side load to be transmitted to the tip. In the tests where the tip rolled over it is likely that the interaction between the blade and rounded edge of the bar caused such a small side load to be applied at the tip.

CATRA sharpness tests

CATRA, Sheffield, have also devised a method, BS EN ISO 8442-5 that is used as a standard for blade sharpness. During this test, a sample blade is made to cut through a stack of abrasive impregnated paper of known depth and specification. As the edge of the test blade is blunted this would be considered a destructive test and would not be appropriate for our application. However, this method was used to obtain 3 different levels of bluntness for the Stanley® test blades. The blades were blunted by cutting into the stack of abrasive impregnated paper a set distance in millimetres (cut length). The longer cut lengths i.e. more blunting, were achieved by making several passes through the same depth of the stack of paper with each blade.

Razor Edge Durability and Sharpness test (REDS)

REDS is a less severe test method used by CATRA for testing razor blades. A razor blade is pressed a known distance into a soft material and the load on the blade is recorded. In the REDS test the material used is a specified grade of silicone rubber. A peak load is recorded during the test and this peak load is quoted as the sharpness indicator. A low peak load value indicates a sharp blade and a high value a blunt blade. This interpretation of results is similar to the Rockwell® tip sharpness test.

Comparison of test methods

CATRA's REDS test and the Rockwell based test were compared using 40 Stanley® blades type 1992. Ten of these blades were left in their "sharp" straight out of the packet condition. The remaining 30 were subjected to 3 different degrees of blunting on the BSI sharpness tester described above. All 40 blades were tested for edge sharpness against the CATRA razor test and the sharpness index recorded for the blades in their "sharp" and blunted condition. These 40 blades were then tested for edge sharpness on the Rockwell sharpness tester and the values recorded. The results from this trial are summarised in the following charts:

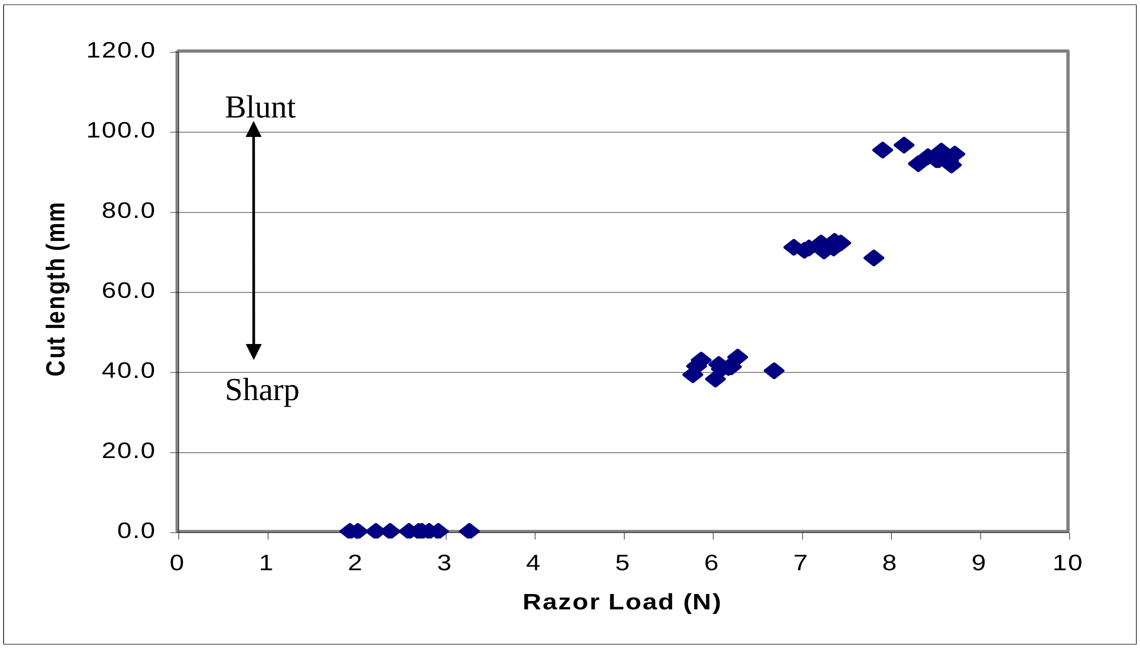

Figure 7. Chart indicating the variance with respect to blunting (cut length) of the Razor load in the CATRA REDS test.

The first blunting of the blades on both tests shows the largest drop in sharpness values. The Rockwell® readings change an average of 6 points and the loads in the CATRA razor test change by 3.5N more than double the average "sharp" value of 2.6N. As the blades become more blunt the CATRA test shows an average change of about 1N per blunting and the Rockwell® test changes an average of about 2 points.

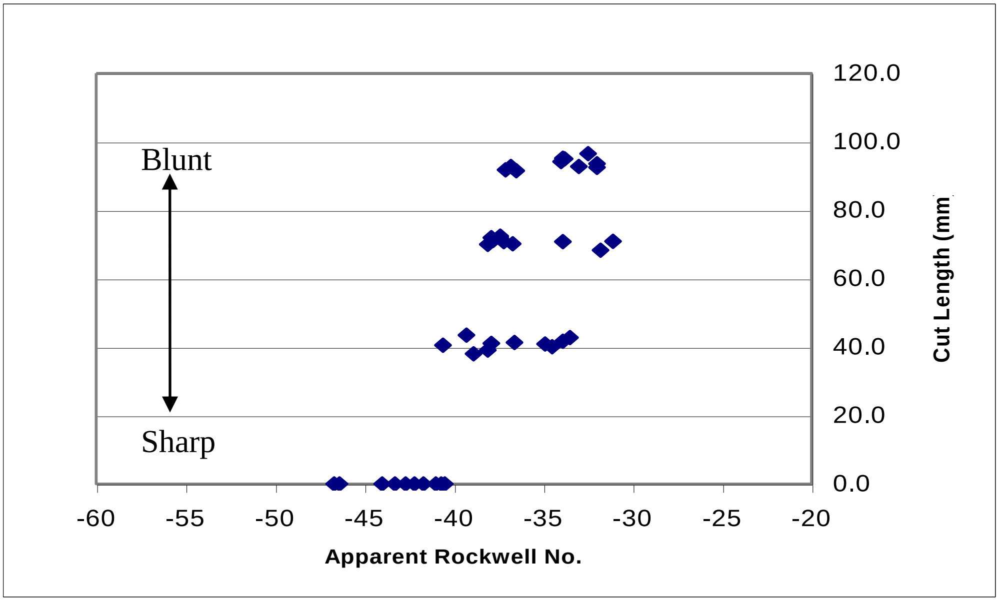

Figure 8**:** Chart indicating the variance with respect to blunting (cut length), of the Rockwell® Number, in the modified Rockwell® test.

Both methods of measuring edge sharpness indicate a difference between “sharp” (new) and blunt blades as shown in figures 7 and 8. The CATRA test differentiates between the 3 degrees of blunting and gives repeatable sharpness values with a variation within one Newton, figure 7. The variation in sharpness readings within each degree of blunting in the modified Rockwell® test is between 7 and 8 superficial Rockwell® points. As the total variation between sharp and blunt blades is only 17 Rockwell points, this variation was too great to be able to determine different degrees of blunting.

Latest CATRA Edge Sharpness Machine

The CATRA machine for BS EN ISO 8442-5 used in these trials is costly and a more reasonably priced prototype machine was subsequently designed and built to undertake the measurement of edge sharpness for Stanley blades®. The prototype machine is illustrated in figure 9 using the same grade of silicone rubber as used in the razor test described above. The effectiveness of other test media such as polymeric film are currently being evaluated as an alternative to silicone rubber. The repeatability of sharpness is in the order of 0.02N and typical cutting forces of new razor blades are between 1N and 1.5N. The sharpness cutting force is displayed on a digital readout. The unit can be linked to a PC for data logging. A typical time per test is about 2 minutes per blade

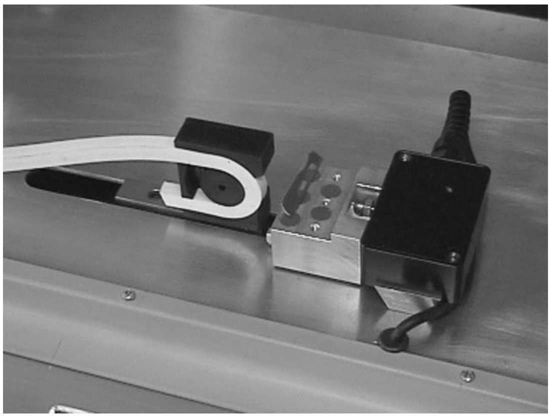

Figure 9. CATRA prototype sharpness measurement machine

The modification to the current Rockwell® tip sharpness test was able to show the difference between sharp and blunt Stanley® blades. Although it is primarily a quantitative method of measurement, it could be a viable and cost effective method of measuring edge sharpness for a slashing blade for current users of the PSDB[3] and NIJ[4] knife tip sharpness test. As a test block the round bar was found to be unsuitable for measuring tip sharpness as the interaction between the blade and the geometry of the bar caused the tips of some blades to roll over. The current tip sharpness test method for PSDB blades using a flat test block is recommended, as the flat block does not damage the blade. Adapting the CATRA razor test for edge sharpness measurement of Stanley® blades was found to be very successful. This is a consistent and repeatable test that may also be easily adapted to measure tip sharpness.

References:

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