ANALYSIS OF SKIN PROTECTION OFFERED BY DIFFERENT MATERIALS IN IMPACTS BY SHARP BLADES

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ABSTRACT

The protective capabilities of various fabrics and materials in preventing skin lacerations from impacts with sharp blades have been evaluated. A wooden mandril was covered with 100 - 150 layers of low density polyethylene sheets (0.09 mm thick) to simulate human skin, and this was then covered with the protective material to be tested. Various materials were impacted with steel blades at velocities of 3.1 to 6.3 m/s. The materials included cotton and synthetic fabrics, leather sheets, jute, knitted nylon acrylate mixtures, non-woven polypropylenes, canvas and kevlar-stainless steel weave material. Closely woven thick cotton fabrics were found to be relatively the most effective in preventing lacerations. People using hand tools and sharp blades can protect lacerations by wrapping their limbs with two or three layers of closely woven fabric.

IN A STUDY of agricultural workers in nine villages of Haryana, India, it was found that in one year 2164 persons sustained injuries out of a total population of 23,000 (Varghese and Mohan, 1990). A total of 572 injuries were related to agricultural work and 265 (46%) of these were caused by hand tools. A vast majority of these injuries were caused by spades and sickles hitting the hand, lower legs and feet. Many of these injuries could have been mitigated if the limbs were covered by protective sleeves and shoes.

Protective sleeves and gloves have been developed in industrialized nations for workers in factories. Some materials are available for farm workers also. Most of these protective garments and gloves are made from stainless steel wires interwoven with Kevlar yarn. This makes these items relatively expensive and these materials are also heavy and uncomfortable for farm work in tropical climates.

This study was undertaken to test the laceration protection capabilities of materials which could be used to cover human limbs. Comfort, low cost and easy availability of materials were included as important criteria while evaluating the materials.

METHODS

SELECTION OF MATERIAL TO SIMULATE SKIN PROPERTIES - Various polymeric materials were obtained and properties examined for selection of one which simulated skin properties in shear. Shear properties of skin were obtained from literature (Skalak and Chien 1987; Gupta et al. 1993; Gupta et al. 1993; Deck J. David 1976; Sorrells and Berger 1973; Malkin and Askadsky et al. 1990). Low density polyethylene sheets of 0.09 mm thickness combined in layers of 100 and 150 sheets were found to be suitable for simulating skin and sub-cutaneous tissue of 9.0 mm and 13.5 mm thickness respectively. The depth of cut was measured by counting the number of sheets cut after the test.

IMPACT VELOCITIES OF FARMING TOOLS - Impact velocities of farming tools, such as sickles and spades, were obtained by taking video films of people in actual working postures and then the films were analysed for calculating impact velocities. The maximum impact velocities for sickle and spade in their normal working postures were found to be 4.75 m/sec. and 8.83 m/sec. respectively.

SELECTION OF PROTECTIVE FABRICS - A total of 26 materials with different fabric structure were selected and tested for their protective value in blade impacts. Table 1 gives a listing of these materials.

Table 1: Different types of materials tested for its protective value against an impact.

S.No.	Material	Description
1	Closely woven jute fabric	Jute fabric of thickness 1.44mm used for grain storage in rural areas.
2	Raxine upholstery material	Thick knitted cotton fabric with PVC film coating on top. Total thickness of material in 0.8mm.
3	Knee cap	Knitted cotton fabrics with rubberised elastic material woven in it (thickness 1.8mm). It is commonly used for sprain relief.
4	Non woven polypropylene fabric	Thickness 0.31mm.
5	Cotton upholstery fabric	Thickness 1mm.
6	Non woven polyester fabric	Thickness 0.28mm.
7	Loosely woven jute fabric	Commonly used as packaging material with thickness of 0.79mm.
8	Gutta Perch	Rubberised sheet of 0.39mm thickness.
9	Knitted Nylon Acrylate mixture fabric	Used for making socks, 0.68mm thick.

Table Contd...

10	Woven polyethylene polypropylene blend fabric	Used in making sacks to store fertilizers, thickness 0.24mm.
11	Non woven polypropylene fabric	Thickness 1.12mm.
12	Loosely woven thick cotton fabric	Used as mopping cloth. Thickness 0.94mm.
13	Polyurethane-leather mixture material with cotton lining	Used for making leather hand gloves. Thickness 1.2mm.
14	Knitted cotton fabric	Used for making cotton socks. Thickness 0.63mm.
15	PVC shoes	Low cost shoes-popular among industrial as well as agricultural workers. Material thickness 2.1 mm to 4.11mm.
16	Oven gloves material	Non-woven cotton fibres sandwiched between woven cotton fabric, thick on top and thin at bottom. Total thickness is 2.44mm.
17	Canvas fabric	Closely woven cotton fabric. Thickness 0.57mm
18	Leather shoes	Material thickness 2.25mm.
19	Industrial Safety shoes (side)	Hard leather sandwiched between two layers of relatively softer leather. Material thickness 3.48mm.
20	Gumboot - Front	Carbon filled natural rubber of thickness 3.6 to 4.6mm.
21	Gum boot - side	Thickness 4.22 to 4.80mm.
22	Closely woven cotton fabric (one layer)	Used as shawl material. Thickness 0.6mm.
23	Closely woven cotton fabric (two layers)	Thickness 1.2mm.
24	Industrial Safety shoes (front)	Metal sheet of 1.7mm thickness sandwiched between leather sheets, 2mm thick on top and 2.44mm thick on bottom.
25	Kevlar stainless steel glove	Used by workers in industrial meat processing units. Thickness 2.1mm.
26	Closely woven cotton fabric (three layers)	Same as item No. 22. Thickness 1.8mm.

IMPACT TESTING SET-UP - Figure 1 shows the test set-up. A semi-cylindrical wooden mandril is covered with a skin substitute of polyethylene sheets. For a drop height of 0.5 m we used 100 layers of the sheets and for drop heights of 1 m and 2 m, 150 sheets were used. The polyethylene sheets were covered with fabrics of different properties and impacted with sharp edged blades. The mandril was placed on a platform resting on a dynamic force transducer (Kistler) and impacted with a blade (total weight of assembly - 2.5 kg) at different velocities. The impact force on the mandril was recorded by the force transducer. The following tests were conducted:

(i) Thickness of skin like covering - 9.0 mm to 13.5 mm
(ii) Skin covered with different test fabrics.
(iii) Drop heights of 0.5 m, 1.0 m and 2.0 m gave nominal impact velocities of 3.1, 4.4 aqnd 6.3 m/s respectively.
(v) Blades had tip angles of 30, 50 and 70 degrees
(vi) All fabric samples were tested with blades having 30, 50 and 70 degree tip angles from a drop height of 1 metre (4.4 m/s). Based on the results, better materials were selected for impacts with a 2 m drop height (6.3 m/s) with with blades having 50 degree tip angles.

The depth of cut and impact force were the main criteria used for judging laceration protection properties of various covering materials.

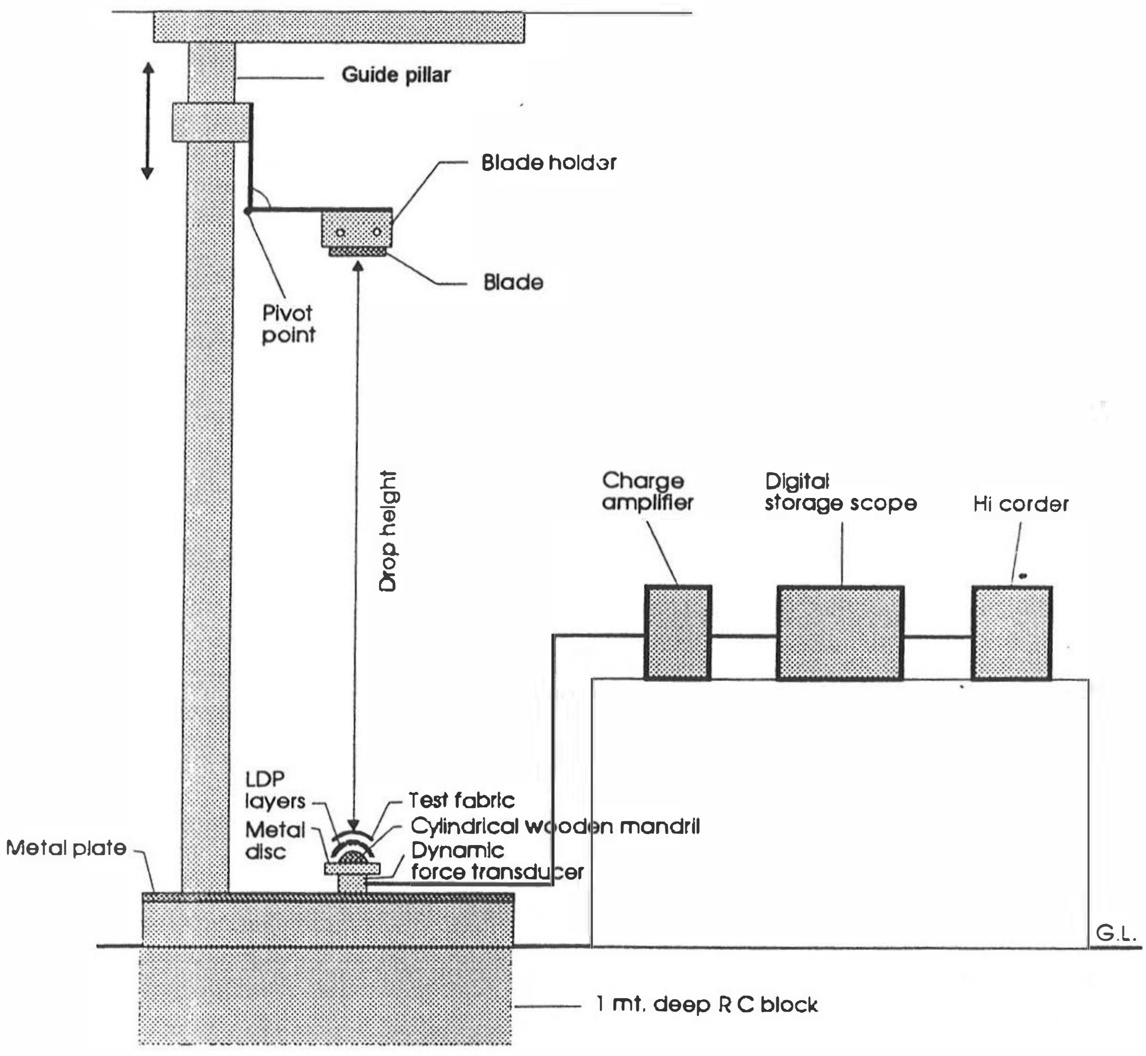

Figure 1: Schematic diagram of the test set-up

RESULTS

Table 2 shows the performance of all the materials tested for impact velocity of 4.4 m/s. Figures 2, 3 and 4 show the performance of different materials comparing the average impact forces and depth of cut for each test condition. Figure 5 shows the comparative performance of the few selected materials tested for blade impact velocity of 6.3 m/s.

Table 2: Comparative Performance of the Test Materials for the Impact Tests with Drop Heights of 1 metre.

Material Code No.	Average Maximum Force (kN)			Average Time (ms)			Average layers cut (No.)		
	30° blade	50° blade	70° blade	30° blade	50° blade	70° blade	30° blade	50° blade	70° blade
1	4.5	4.5	3.2	7.9	8.2	12.8	37.5	49.5	88.0
2	3.6	2.0	4.4	6.2	10.4	6.0	69.0	123.0	86.5
3	4.0	3.4	3.4	8.0	7.8	6.4	54.0	84.5	72.5
4	3.0	5.1	6.6	7.2	10.4	10.4	123.5	133.0	120.6
5	4.4	4.8	4.7	9.0	8.0	6.1	49.5	135.0	91.5
6	3.4	3.5	3.4	6.2	8.0	5.8	69.5	59.0	91.0
7	4.8	1.7	2.0	5.4	7.7	8.2	53.5	118.0	118.0
8	2.6	2.4	2.1	6.1	7.7	8.0	93.5	97.5	147.0
9	2.6	2.9	4.6	5.4	7.0	6.0	60.0	86.0	78.0
10	3.2	2.5	2.2	5.1	8.7	7.8	50.5	120.5	114.5
11	3.4	3.9	6.5	6.4	6.4	4.9	87.0	81.5	45.0
12	4.2	4.1	5.0	5.7	5.6	5.1	53.0	54.0	55.5
13	6.9	4.8	5.9	3.8	9.6	7.8	4.5	106.5	25.0
14	1.4	5.6	7.6	4.4	5.8	5.8	43.0	65.0	78.5
15	3.7	3.1	3.7	11.0	10.6	9.0	46.0	95.0	90.5
16	7.2	6.4	8.2	4.1	6.9	4.4	0.0	37.5	6.0
17	5.5	5.5	3.2	5.1	9.1	6.4	38.5	80.5	68.0
18	4.2	4.4	8.0	8.0	9.2	5.0	120.0	90.0	10.0
19	6.0	4.6	9.2	6.6	10.0	6.6	59.0	75.0	43.0
20	4.0	4.2	5.4	6.6	7.2	10.4	16.0	16.0	25.0
21	4.0	6.2	7.4	8.0	7.4	7.8	26.0	18.0	42.0
22	5.2	8.1	4.8	4.6	4.7	6.3	35.0	61.5	46.0
23	6.4	7.2	8.4	12.4	4.0	4.6	16.0	33.0	34.0
24	4.0	11.0	52.9	6.4	4.4	4.2	0.0	0.0	0.0
25	5.0	7.0	9.0	11.0	4.6	5.0	0.0	16.0	19.0

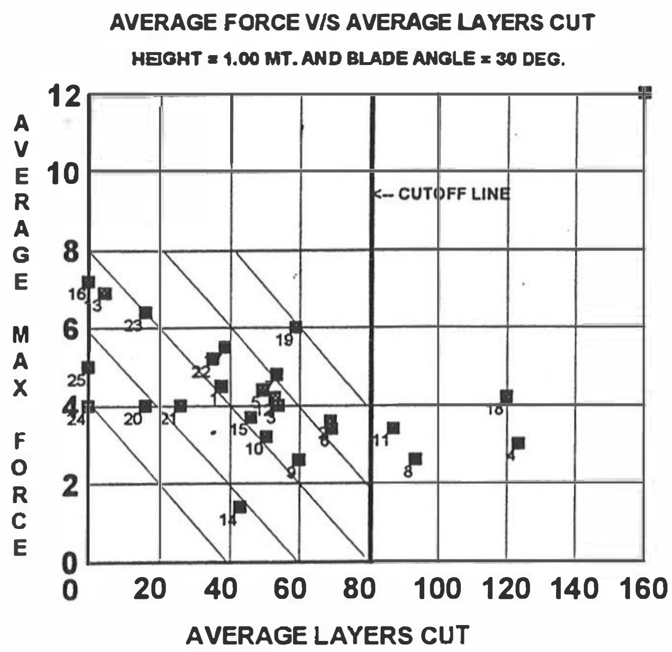

Figure 2: Performance by average force v/s average layers cut for tests with 1 metre drop height and 30 degree blade angle

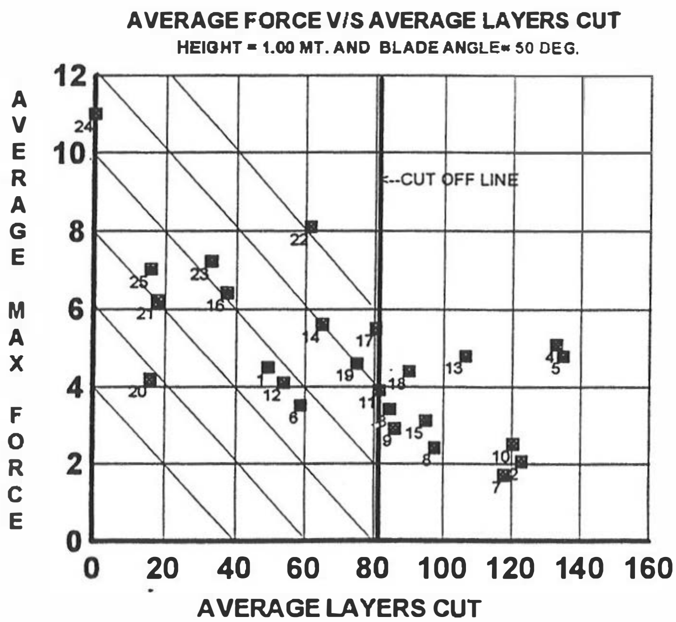

Figure 3: Performance by average force v/s average layers cut for tests with 1 metre drop height and 50 degree blade angle

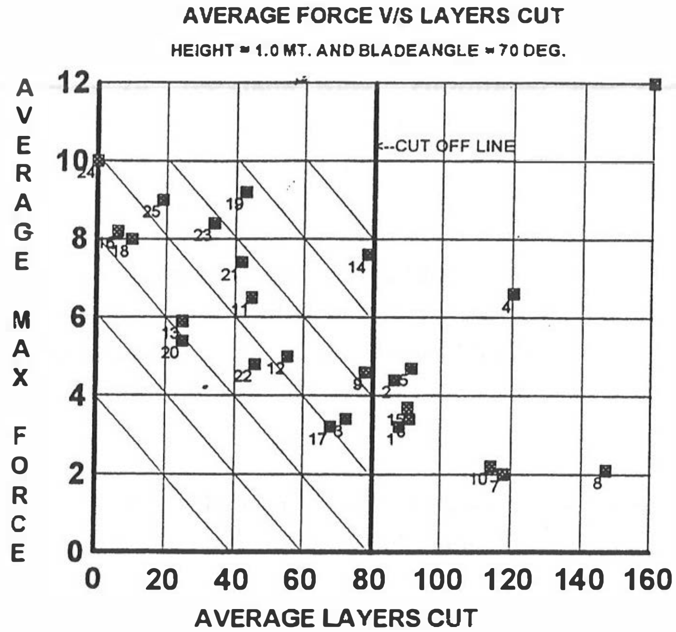

Figure 4: Performance by average force v/s average layers cut for tests with 1 metre drop height and 70 degree blade angle

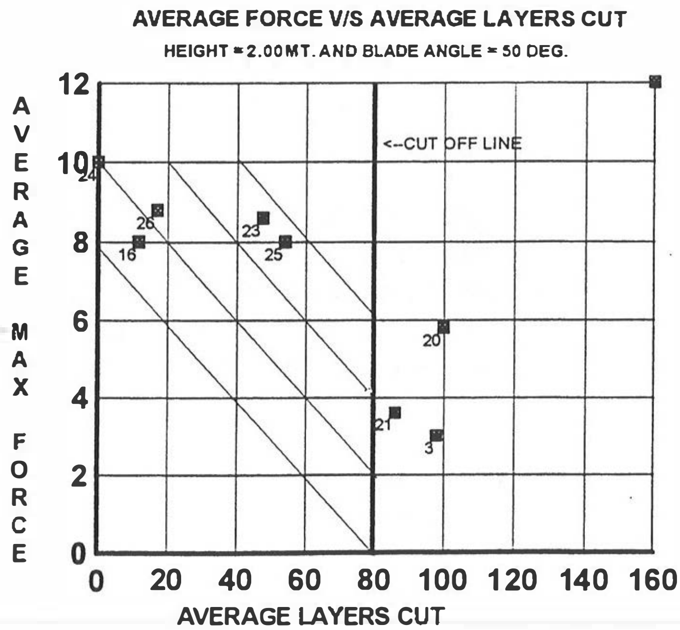

Figure 5: Performance by average force v/s average layers cut for tests with 2 metre drop height and 50 degree blade angle

RANKING CRITERIA- The values of average maximum force v/s average layers cut for different test conditions were analysed to give a comparative ranking order of the test materials. To give appropriate weightage to average maximum force and average layers cut the chart area was divided in diagonal bands. Comparative ranking was based on the following criteria.

i) Materials falling in the higher bands would be considered less protective than the materials falling in the lower bands. A material placed in the bottom most band will would have the best rank because it would have recorded the minimum average impact force and minimum average layers cut.

ii) In the same band, the materials which recorded fewer layers cut were given preference over materials which recorded similar impact forces but greater number of cut layers.

Tables 3 and 4 show comparative ranking of the materials with blade drop heights of 1 m and 2 m respectively.

DISCUSSION AND CONCLUSIONS

LOWER LIMB PROTECTION - The feet of the agricultural workers are more likely to sustain injuries from implements like spades, hoe, axe etc. These implements can have higher impact velocities and associated energy levels than tools such as sickles, scythes and knives. For lower limb protection only those materials were considered which performed well in tests which had blade drop heights of 1 m and 2 m. Tables 3 and 4 clearly shows that only two materials i.e. industrial safety shoes and gumboots can be recommended for protecting the feet. Ordinary leather and PVC shoes which are commonly used by agricultural workers do not provide adequate protection. The shank can be protected quite effectively by wrapping multiple layers of thick cotton fabric. Thick coottton fabric is easily available and is also very comfortable in hot and humid conditions. Materials which use Kevlar inter woven with stainless steel can also give adequate protection but can not be recommended for situations where cost is a major criterion and also in environments which involve hot and and humid conditions.

UPPER LIMB PROTECTION - Injuries to upper limbs of agricultural workers are most commonly caused when working with implements such as sickles, scythes and knives. These situations are associated with lower impact speeds and energies than those described in the paragraph above. Tables 3 and 4 clearly indicate that the following can be used as protective fabrics to minimise the probability of injuries to the hands and arms of agricultural workers:

Hand protection - canvas and oven type glove material modified for use by agricultural workers. These gloves need not have finger and thumb covering for greater maneuvarability and the gloves can extend above the wrist.

Table 3: Comparative ranking of materials for tests with blade drop height of 1 m (4.4 m/s)* .

Code No.	Material	Comparative ranking for impact test with blade angle			Average	Overall rank
		30°	50°	70°		
20	Gum Boot(Front)	3	1	1	1.666	1
24	Safety Shoes(Front)	1	7	2	3.333	2
25	Kevlar S.S. gloves	2	3	8	4.333	3
16	Oven gloves	5	9	3	5.666	4
21	Gum Boot(Side)	8	2	10	6.666	5
23	Thick cotton fabric (double layer)	7	8	9	8.000	6
22	Thick cotton fabric (single layer)	9	12	6	9.000	7
14	Cotton socks	4	10	16	10.000	8
17	Canvas gloves	11	13	7	10.333	9
12	Loosely woven cotton fabric	15	5	12	10.666	10
13	Leather gloves	6	25	5	12.000	11
1	Closely woven jute fabric	10	4	25	13.000	12
19	Safety shoes (Side)	19	11	14	14.666	13
6	Non woven polyester fabric	21	6	25	17.333	14
3	Knee cap	16	25	13	18.000	15
18	Leather shoes	25	25	4	18.000	15
9	Nylon acrylate mixture	17	25	15	19.000	16
11	Non woven polypropylene (thick)	25	25	11	20.333	17
15	PVC shoes	12	25	25	20.666	18
5	Cotton upholstery	13	25	25	21.000	19
10	Woven LDP & PP blend	14	25	25	21.333	20
7	Loosely woven jute	18	25	25	22.666	21
2	Raxine	20	25	25	23.333	22
4	Non woven polypropylene (thin)	25	25	25	25.000	23
8	Gutta perch	25	25	25	25.000	23

* When a test failed (i.e. all the polyethylene layers were cut) the tested material was given a ranking of 25.

Table 4: Comparative ranking of materials for tests with blade drop height of 2 m (6.3 m/s).

Code No.	Material	Rank
24	Industrial Safety Shoes - Front	1
16	Oven Gloves Material	2
26	Closely Woven Cotton Fabric (Three layers)	3
23	Closely Woven Cotton Fabric (Two layers)	4
25	Kevlar Stainless Steel Glove	5
20	Gum Boot - Front	6

Arm protection - thick cotton fabric can be wrapped in multiple layers. Specially designed Kevlar S.S. material can be used where material costs are not critical and workers have a cool environment.

Allother materials such leather sheets, leather gloves, orthopaedic knee cap material, jute and nonwoven synthetic materials were found to be unsatisfactory.

As cotton is a proven biocompatible material, no tests were conducted to check its biocompatibility.

REFERENCES

Deck J. D. "Skin Histology After Cuts, Punctures and Related Injuries. Report by University of Virginia, U.S.A. 1976.

Gupta A.K.,Rana S.K. and Deopura B.L. Flexural and Impact Properties of High-Density Polyethylene/Linear Low-Density Polyethylene Blend. *Journal of Applied Polymer Science*, 49, 1993, 477-485.

Gupta A.K.,Rana S.K. and Deopura B.L. Mechanical Properties and Morphology of High-Density Polyethylene/Linear Low-Density Polyethylene Blend. *Journal of Applied Polymer Science*, 46, 1993, 99-108.

Malkin A.Y.et. al., Experimental Methods of Polymer Physics, Engelwood Cliffs, Prentice Hall, 1990.

Richard S. and Shu Chien, Handbook of Bioengineering, New York, McGraw Hill, 1987.

Sorrells J.R. and Berger. R., Some Cutting Experiments on Human Skin and Synthesis Materials, Report by National Bureau of Standards, Dept. of Commerce, Washington D.C., U.S.A., 1973.

Varghese M. and Mohan D., Occupational Injuries Among Agricultural Workers in Rural Haryana, India, *J. Occupational Accidents*, 12, 1990, 237-244.