50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. OFR 21-88.	2.	3. Recipient's Accession No. PB88-209333

4. Title and Subtitle	5. Report Date
PERSONAL EQUIPMENT FOR LOW SEAM COAL MINERS: X. IMPROVED KNEE PADS, A MODIFIED DESIGN	March 1986
	6.

7. Author(s)	8. Performing Organization Rept. No.
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9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Essex Corporation Human Factors and Training Systems Group 741 Lakefield Road, Suite B Westlake Village, CA 91361	11. Contract(C) or Grant(G) No. (C) J0387213 (G)

12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
U.S. Bureau of Mines P/BAO, Section of Procurement 4800 Forbes Avenue Pittsburgh, PA 15213	Final Report 1982-1986
	14.

15. Supplementary Notes

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16. Abstract (Limit: 200 words)

The purpose of this work was to develop and field test improved knee protection for underground coal miners working in low seam mines. In a previous phase of this contract (Sanders, 1982), experimental knee pads were developed and field tested. The field test revealed several design deficiencies with the knee pads, and suggestions for improving the design were made. The work summarized in this report, therefore, consists of modifying the design and method of fabrication of the knee pads originally described by Sanders (1982), and of field testing the improved design.

The new prototype was shorter and wider than the original design, and used a neoprene pass-through strap design rather than a cloth strap molded into the pad itself. The new prototype was constructed by slush molding a hollow bladder that was then filled with foam.

Initial reactions to the pads in the field test were very positive. However, after two months, the opinions about the new prototype became less positive. They were judged, generally, to be no better or worse than the pads usually worn by the field-test participants. Problems were encountered in the field with respect to durability. Water seeped into the inner cavity of many of the pads and caused the foam to deteriorate. It was concluded that it would not be cost-effective or feasible to significantly improve upon current commercially available knee pad designs.

17. Document Analysis a. Descriptors

Underground Coal Mining
Personal Protective Equipment
Knee Pads
Field Evaluation
Human Factors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	Unclassified	22
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse

(Formerly NTIS-35)
Department of Commerce

FOREWORD

This report was prepared by Essex Corporation, Human Factors and Training Systems Group, 741 Lakefield Road, Suite B, Westlake Village, CA, 91361, under USBM Contract number J0387213. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Pittsburgh Research Center with Mr. Thomas Bobick acting as Technical Project Officer. Ms. Gerry Puskar was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period 1982 to 1986. This report was submitted by the authors in March 1986.

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1.0 INTRODUCTION

The work summarized in this report was performed under Contract J0387213, awarded by the U.S. Bureau of Mines, Pittsburgh Research Center to Essex Corporation.

1.1 Purpose

The purpose of this work was to develop and field test improved knee protection for underground coal miners working in low seam mines. In a previous phase of this contract (Sanders, 1982), experimental knee pads were developed and field tested. The field test revealed several design deficiencies with the knee pads, and suggestions for improving the design were made. The work summarized in this report, therefore, consists of modifying the design and method of fabrication of the knee pads originally described by Sanders (1982), and of field testing the improved design.

1.2 Overview

The project was divided into two phases. The first phase consisted of modifying the design and method of fabricating the knee pads to overcome the deficiencies uncovered by Sanders (1982). The second phase was a field test carried out at four low seam coal mines. The initial problem identification and assessment of the state-of-the-art in knee pad design was reported by Sanders (1982) and will not be included in this report.

1.3 Organization of the Report

The next section of this report (2.0) briefly summarizes the results and recommendations of the first knee pad study reported by Sanders (1982). This information sets the stage for the redesign effort reported in Section 3.0. Section 4.0 discusses the results of the field evaluation of the modified knee pads. The final section (5.0) presents the conclusions of the study.

2.0 SUMMARY OF FIRST KNEE PAD STUDY

Sanders (1982) designed prototype knee pads with the following unique design features:

1. "V" shaped foam pads;
2. Durable, hard outer shell;
3. High side walls;
4. Cut-out for accommodating the thigh while in standing posture;
5. Single strap design;
6. Wide, soft strap;
7. Belt buckle single-prong strap attachment; and
8. Air cushion.

The field test of these knee pads revealed problems that caused the test to be terminated after only one day. The major problem was that the inner "V" shaped pad split or separated from the hard outer shell. In addition, comments and survey responses from the field-test participants identified other needed improvements in the design of the pads. Despite the problems, however, the participants expressed favorable opinions concerning the "V" shape of the inner pad, the high side walls, and the single strap construction. The air cushion, however, did not seem to significantly improve the comfort of the pads.

Sanders (1982) recommended the following modifications be made to the prototype pads to improve their acceptability to mine workers:

1. Increase the inner pad durability.
2. Make the pad wider.
3. Shorten the length of the pad.
4. Shape the side walls to slope down in the back.
5. Make a wider and deeper cut-out in the front to accommodate the thigh while walking.
6. Use an elastic or rubber strap.
7. Construct the knee pad so that the strap passes through the pad and can be slipped around or replaced.

3.0 IMPROVED PROTOTYPE KNEE PADS

Based on the recommendations set forth by Sanders (1982) and presented in Section 2.0 of this report, a new improved prototype design was developed. As it turned out, however, the major problem in the redesign effort was increasing the durability of the pad.

3.1 Increasing Durability

A series of tests were conducted using self-skinning foam that, as it cools, forms a hard shell or skin on all outer surfaces. Despite numerous attempts, however, all the pads produced were too hard and provided no cushioning effect to the wearer. Attempts were made to glue a soft inner pad to the outer shell, but without success. Finally, a two-process fabrication procedure was discovered that appeared to yield good results.

The process involved slush-molding a hard shell and then filling the interior of the shell with soft foam. The slush-molding process yields a hollow, thin-walled shell. The shell incorporates the outer wall of the pad and the inner cushion in a single unit. An open-cell foam is then injected into the space created for the inner pad. Figure 3.1 shows a cut-away view of the prototype with the foam-filled inner cavity. The advantage of the process is that the knee pad is essentially a single unit rather than an outer shell and an inner pad. This makes it more difficult to split or separate the shell from the pad. In addition, the slush mold creates a hard, durable, outer surface, while maintaining a soft, pliable inner surface for the knee to rest upon.

3.2 Design of the Improved Prototype

Figure 3.2 shows the improved knee pad and the original prototype developed by Sanders (1982). Table 3.1 presents a comparison of the dimensions of the two designs. The following is a list of differences between the original and the improved prototype. The improved prototype:

1. is shorter than the original.
2. is wider than the original.
3. has thinner high side walls.
4. has a wider cut-out in the front to accommodate the thigh when standing.
5. uses a neoprene strap rather than a nylon strap.
6. has a pass-through strap that slips through and can be replaced rather than being molded into the pad itself.
7. has side walls that slope down in the back.
8. is constructed as a single molded unit rather than as two pieces.
9. has a more shallow "V" shaped inner surface.

The improved prototype, therefore, incorporated all the recommendations suggested by Sanders (1982). The improved prototype was less bulky, more durable, and incorporated an improved strap design (neoprene with pass-through construction).

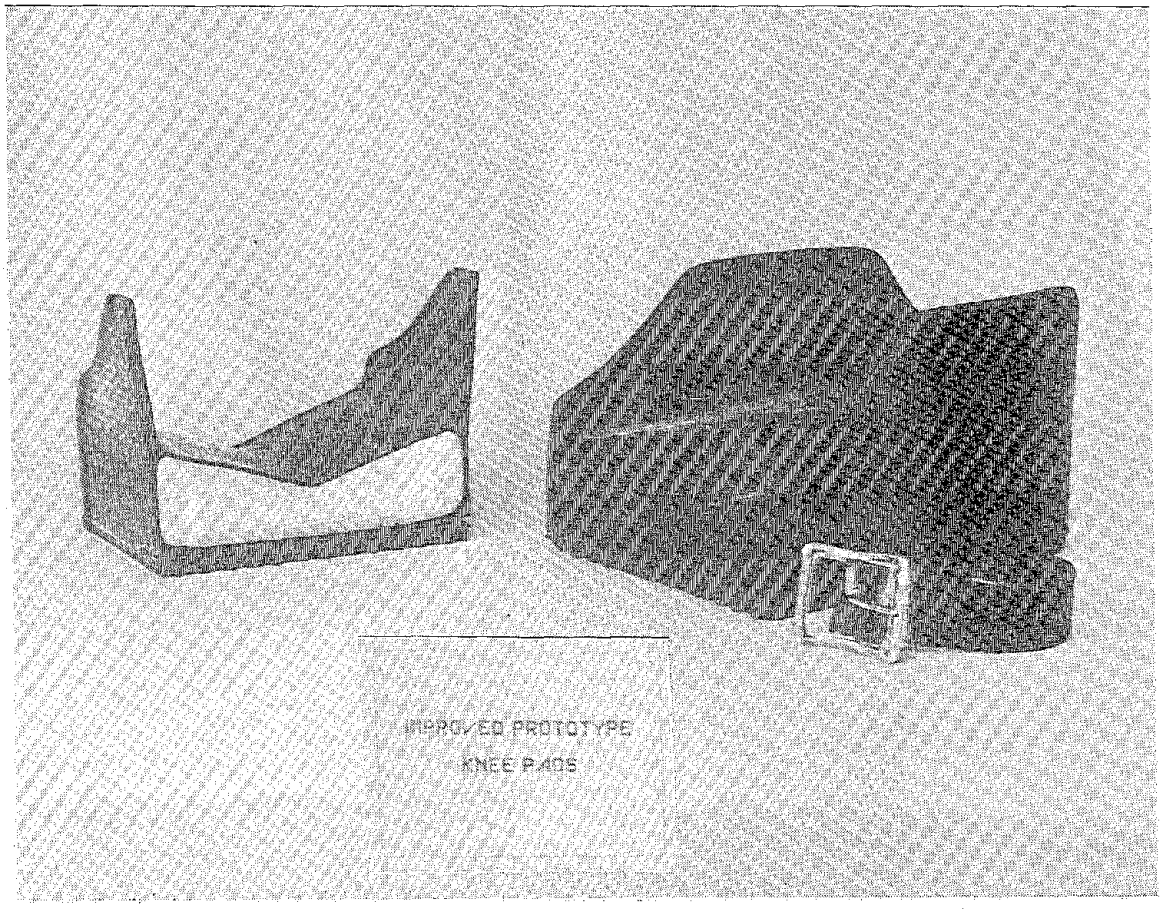

Figure 3.1. Cut-away view of prototype knee pad showing the foam-filled inner cavity of the slush mold.

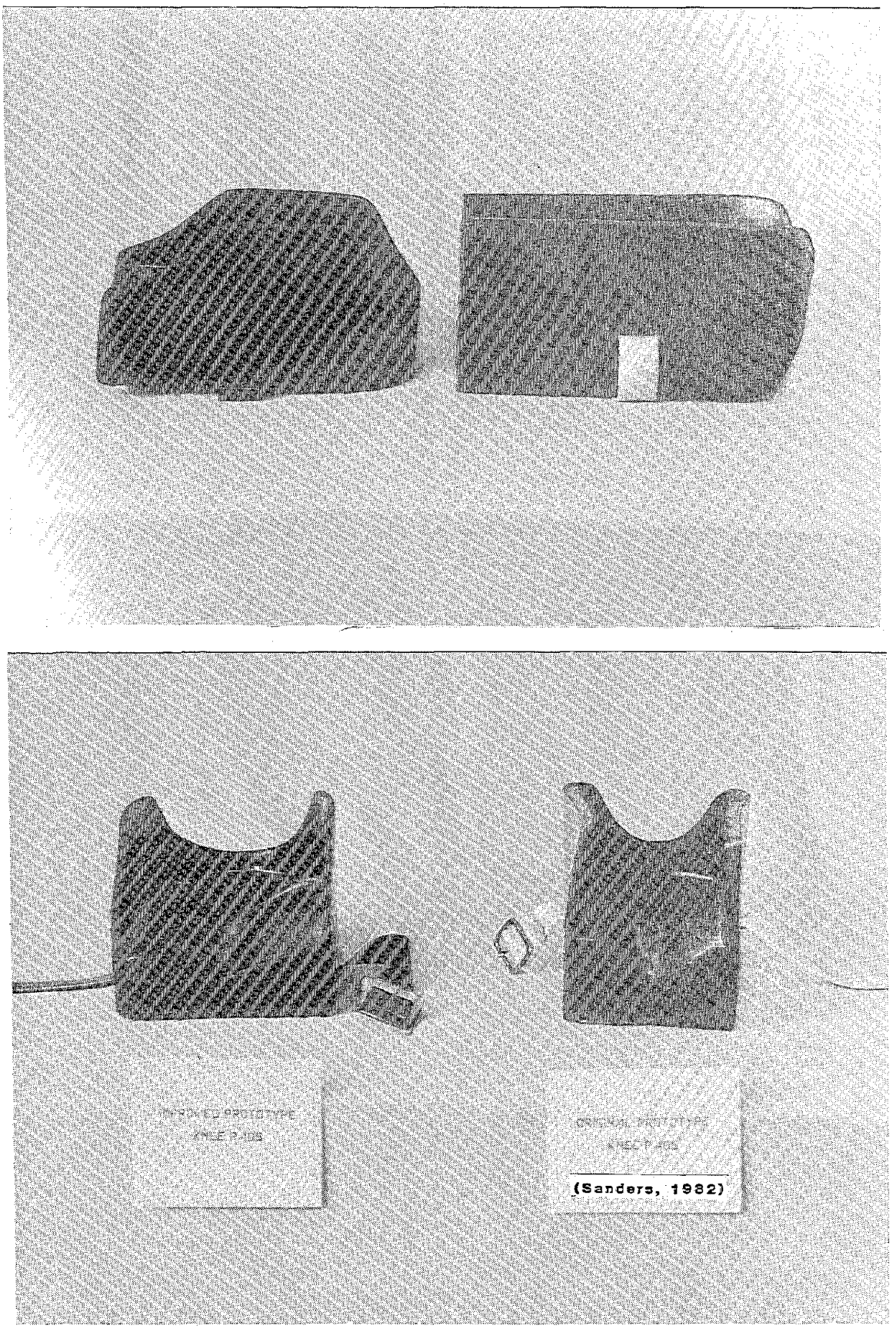

Figure 3.2. Improved and original prototype knee pads. The original was developed by Sanders (1982).

Table 3.1. Comparison of the Dimensions of the Improved and Original Prototype Knee Pads

Dimension	Original Prototype (Sanders, 1982)	Improved Prototype
Overall outside length (cm)	23.0	20.5
front width (cm)	11.1	12.5
rear width (cm)	10.1	12.5
height (cm)	11.3	10.7
Inside length (cm)	22.5	20.0
front width (cm)	9.5	11.5
rear width (cm)	8.5	11.0
Minimum pad thickness (cm)	2.2	2.5
Maximum pad thickness (cm)	4.8	4.3
side wall thickness (cm)	0.8	0.4
weight (kg)	0.55	0.51

4.0 FIELD TEST

The knee pads were distributed to 51 workers at four underground low seam coal mines. Seam height was between 30 and 42 inches. The participants completed two questionnaires. The first questionnaire was completed after using the prototype knee pads for one to two shifts. The second questionnaire was completed after wearing the knee pads for 2 months. Both questionnaires contained a 5-point rating scale on a number of dimensions with which the respondent compared the prototype knee pads with the pads he or she normally wore.

4.1 Demographics

Table 4.1 presents the basic demographic information on the sample of workers participating in the field test. Figure 4.1 shows the distributions of their experience underground, at their mine, and in their job title. All types of jobs were represented in the sample, including general laborers, equipment operators, maintenance workers, and supervisors.

4.2 Crawling and Knee Pad Information

Figure 4.2 presents the distribution of respondents by number of hours per day they spent crawling. Almost 60% of the participants spend 5 or more hours crawling during the day. The types of conditions encountered while crawling are listed in Table 4.2, along with the percentage of respondents indicating each. The major environmental conditions impacting on knee pad usage were the presence of mud, water, and sharp rocks.

Over half the participants (51.2%) normally used National Mine Service (NMS) foam rubber knee pads. These knee pads are constructed as a single piece of foam rubber and use two leather straps. Thirty-five percent (35%) normally wore Rockmaster knee pads. Rockmaster pads consist of a hard rubber shell and a thin flat layer of sponge rubber; two fabric straps secure the pad to the knee. Figure 4.3 shows the prototype knee pad, along with a National Mine Service and a Rockmaster pad. Overall, the sizes are similar, but the prototype has a thicker cushion pad and higher side walls than the other two models.

4.3 Prototype Evaluation Ratings

Table 4.3 presents the rating scale and the mean ratings for each of the dimensions on both the first and second questionnaires. The means were tested to determine if they differed significantly ($p<.05$) from a rating of 3.0 (both usual and prototype about the same). In addition, statistical tests were performed comparing the means from the first questionnaire to those of the second questionnaire.

Several general conclusions can be gleaned from Table 4.3.

1. The initial response (first questionnaire) showed an overwhelmingly favorable evaluation of the prototype knee pads. On all but three dimensions, the prototype was rated better than the usual pads.

Table 4.1. Basic Demographic Data on Field Test Participants

Variable	Mean	Std. Dev.	Min.	Max.
Age (yrs)	31.6	8.12	21	61
Weight (lbs)	174.4	31.24	127	265
Height (in.)	70.0	3.02	65	76

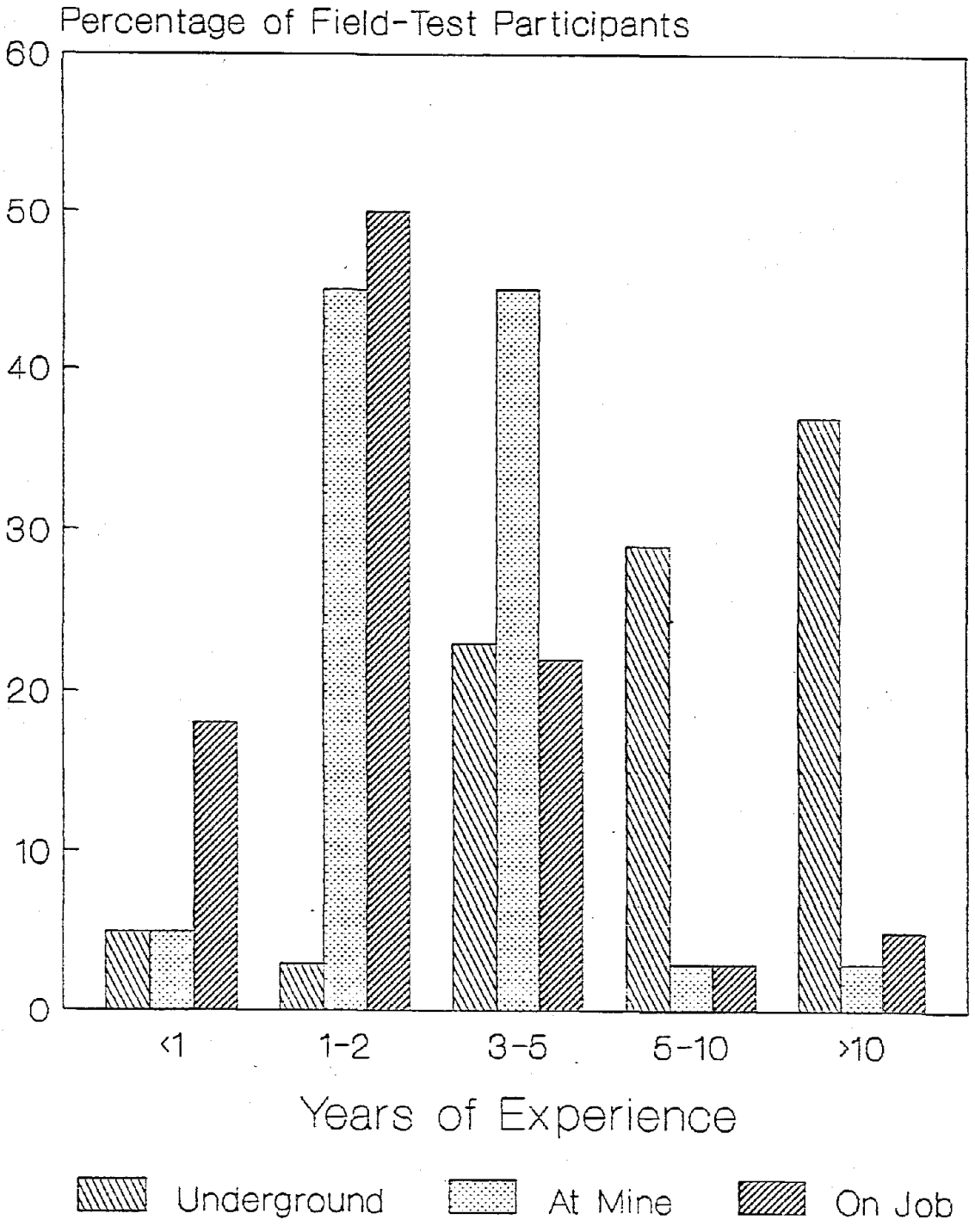

Figure 4.1. Distribution of experience underground, at mine, and in job for field-test participants.

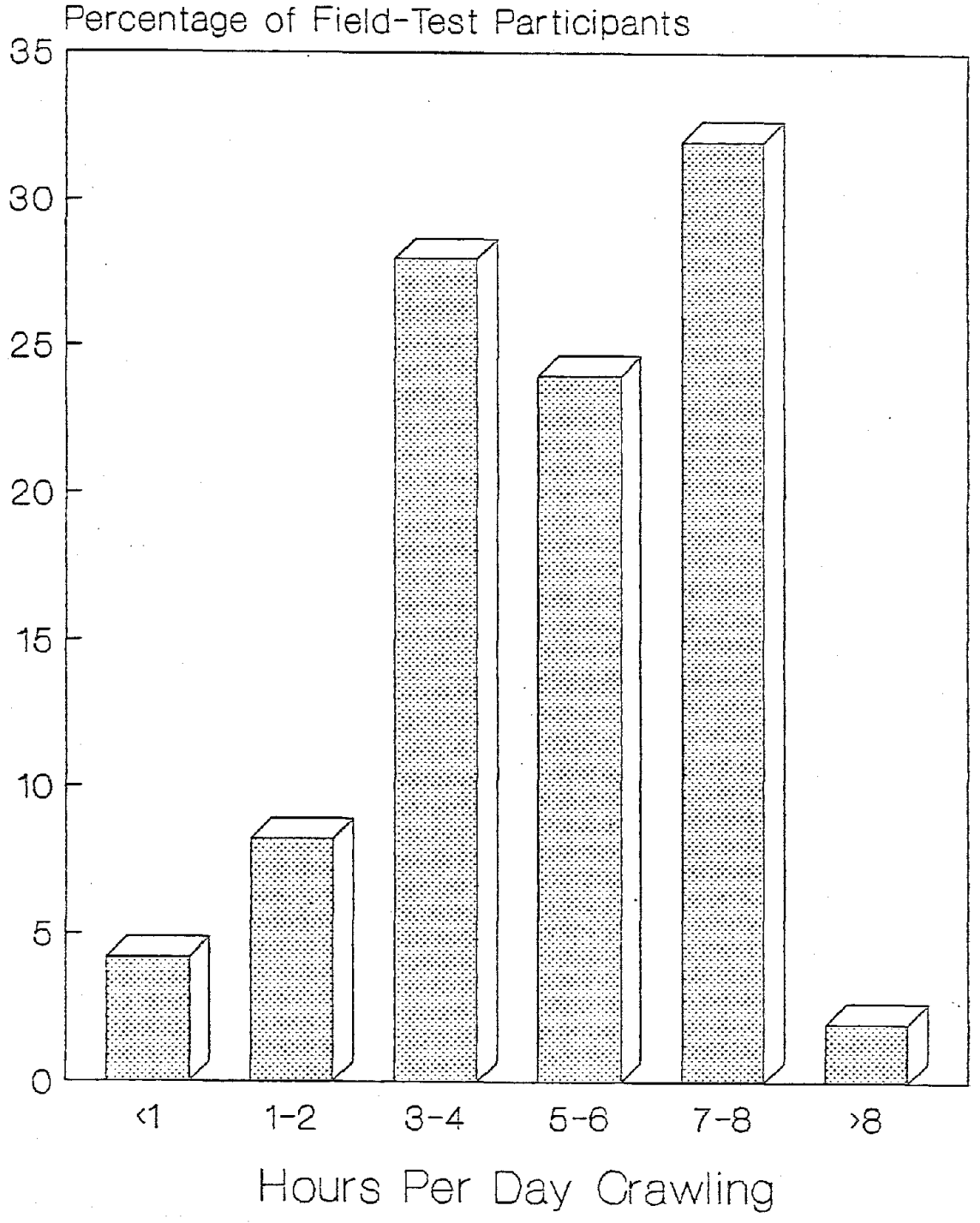

Figure 4.2. Time spent crawling in the mine per day.

Table 4.2. Conditions Encountered While Crawling

Mud	74.5%
Sharp Rocks	56.9
Standing Water	41.2
Hydraulic Fluid	31.4
Oil	11.8

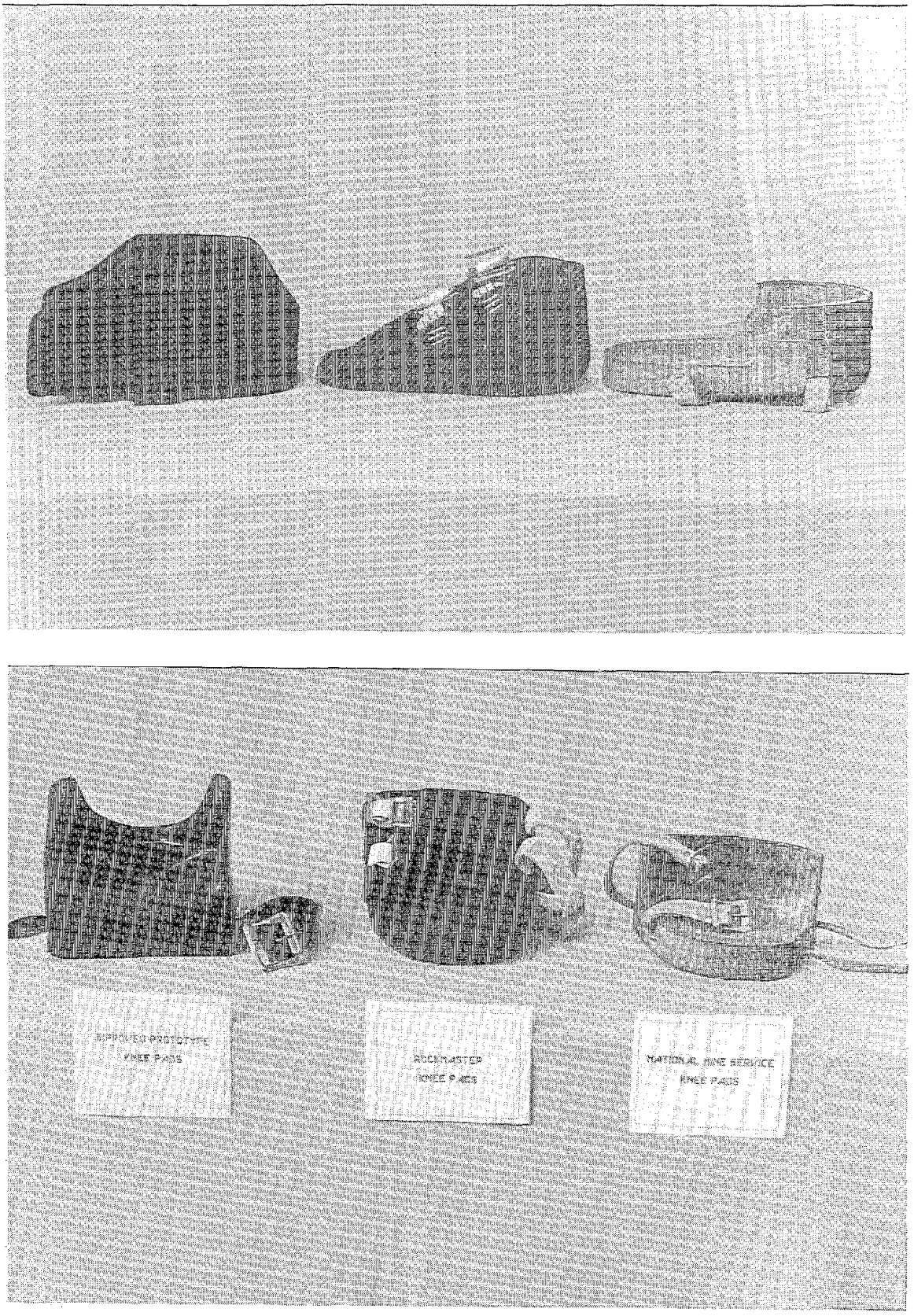

Figure 4.3. Comparison of the prototype with the two types of knee pads usually worn by the field-test participants.

Table 4.3. Mean Ratings for 1st and 2nd Questionnaires Comparing Prototype to Their Usual Knee Pads

Compared to the knee pads you usually wear, how would you rate the new prototype pads on each of the following dimensions. (Use the following scale and write the appropriate number beside each item.)

My usual pads are		Usual and Prototype	The prototype pads are	
Much Better	Somewhat Better	About the Same	Somewhat Better	Much Better
1	2	3	4	5

		Questionnaire		
		1st		2nd
a.	Comfort of the straps	3.30		2.98
b.	Adjustability of the straps	3.37*		2.86
c.	Overall fit of the pads	3.65*	o	2.77
d.	Protection against sharp objects	3.80*		3.44
e.	Prevention of grit and rubble from entering the pad	3.74*	o	2.79
f.	Prevention of rolling off the pads	3.50*		2.63
g.	Prevention of slipping on the floor	3.94*		3.40
h.	Prevention of knee movement inside the pad	3.41*	o	2.67
i.	Prevention of sweating	3.44*		3.09
j.	Comfort while sitting on your knees	3.91*		3.40
k.	Comfort while crawling	4.00*	o	2.98
l.	Comfort while duck-walking	3.38*		3.07
m.	Comfort while walking upright	3.53*	o	3.02
n.	Overall comfort	3.98*	o	2.86
o.	Ease of adjusting the straps while working	3.67*	o	3.07
p.	Ease of putting on and taking off the pads	3.87*		3.63*
q.	Softness of the pad	4.13*		3.88*
r.	Durability of the outer surface	3.76*		3.35
s.	Durability of the straps	3.14	o	2.19*
t.	Physical appearance	3.39		3.05
u.	Overall evaluation	3.65*	o	2.77

*Significantly different ($p<.05$) from a rating of 3.0.

oSignificant difference ($p<.05$) between 1st and 2nd questionnaires

2. By the second questionnaire (approximately 2 months later), opinions about the prototype had become less positive. On all dimensions, the mean ratings for the second questionnaire were lower than those on the first. Nine of these differences reached statistical significance.

3. At the time of the second questionnaire, the prototype knee pads were judged, generally, to be no better or worse than the pads usually worn. Of the 21 dimensions, only three means were significantly different than a rating of 3.0; and on two of them, the prototype was rated higher ("ease of putting on and taking off the pads," and "softness of the pad").

As further evidence of the basic equivalence of the prototype and usual pads, the overall evaluation item on the second questionnaire revealed that 32.6% rated the prototype better than the usual pad, 25.6% said both were about the same, and 41.9% rated the usual pad better than the prototype.

In an effort to explore the results further, the ratings on the second questionnaire were correlated to the number of hours per day the respondent spent crawling. Of the 21 dimensions, only 3 were significantly correlated ($p<.05$) with time spent crawling. The more time the person spent crawling, the lower the ratings tended to be for: Comfort while duck-walking ($r = -0.365$); Softness of pad ($r = -0.356$); and Durability of the outer surface ($r = -0.499$). In addition, mean ratings were compared between those who usually wore National Mine Service pads and those that usually wore Rockmaster pads. The analyses showed no differences between the groups in terms of how the prototypes were evaluated.

4.4 Durability

Despite all the effort put into manufacturing a durable knee pad, problems still occurred in the field test. The major problem was with the hole used to fill the inner cavity of the pad with foam. On many of the pads, the sealant used to plug the hole cracked from the stress of continual use. This permitted water to enter the foam-filled cavity and to be absorbed by the foam. With continual use, the foam disintegrated under the knee. Figure 4.4 shows a photograph of a disintegrated inner foam pad. The top surface of the pad has been cut and peeled back to reveal the foam underneath. The description given by many of the participants was that the pad would "go flat" like a tire, and thus would provide little or no padding or protection.

In a couple of isolated cases, the outer shell actually split or tore; and in a few cases, the straps ripped at the belt holes. For the most part, however, the outer shell held up quite well during the test. The bottom treads showed virtually no sign of wear over the 2-month period.

4.5 Additional Comments

Written comments indicated that the participants especially liked the softness of the pad (until it went flat). The single strap concept, however, was not well received. The most frequent suggestion for improvement was to add a second strap to help stabilize the pad on the knee.

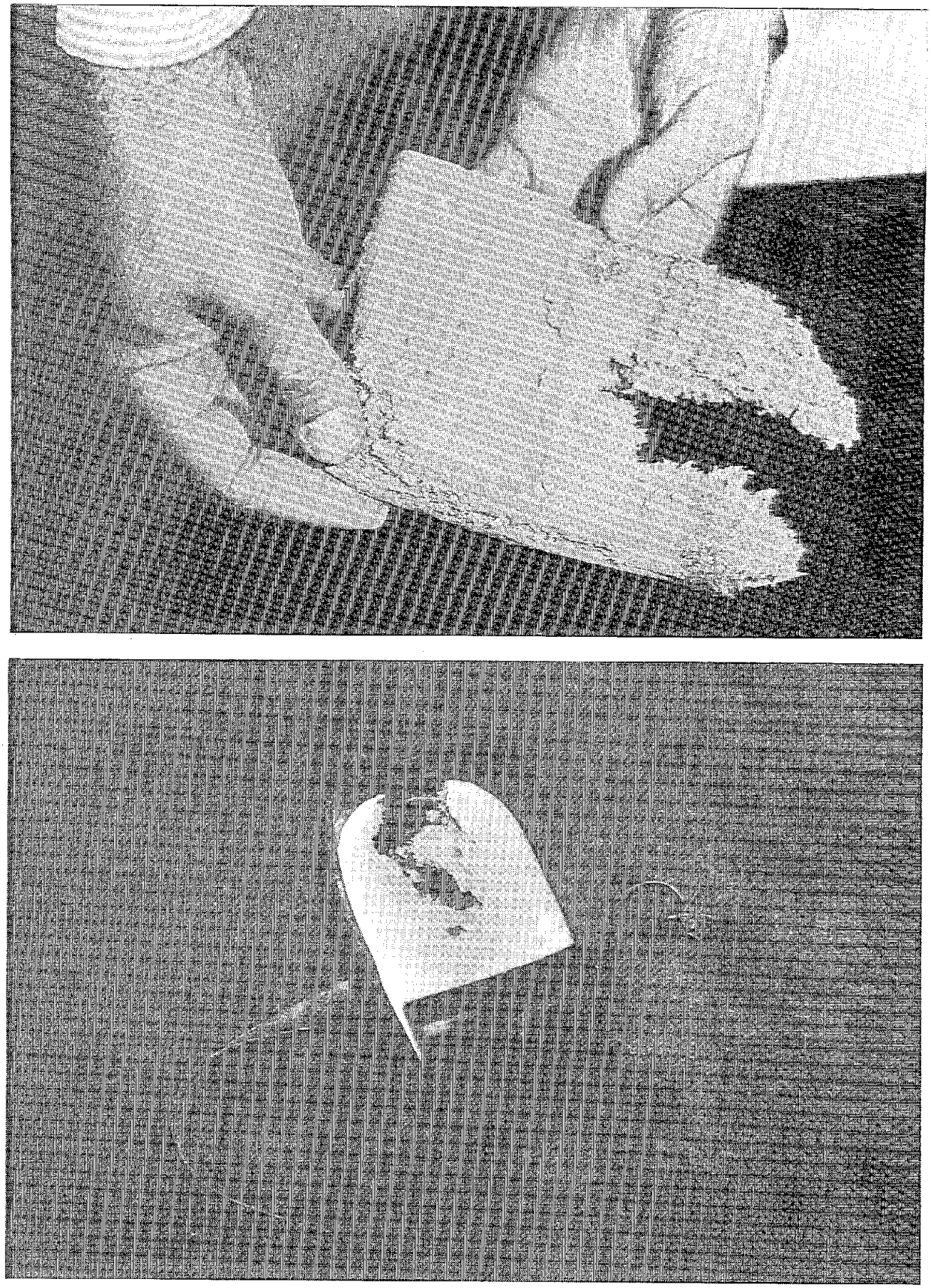

Figure 4.4. Picture of the inside of a knee pad used in the field test. Shown is the deterioration of the inner foam pad under the knee.

5.0 CONCLUSIONS

Despite all the efforts to develop a more comfortable knee pad for underground low seam miners, we must conclude that little or no improvement was attained. The foam and polyvinyl construction used for the prototype did not withstand the punishment and environment encountered in low seam mining.

Although low seam miners deserve more comfortable knee pads than currently available, it does not appear to be cost effective or feasible to significantly improve upon the current designs.

6.0 REFERENCES

Sanders, M. S. (1982). Personal equipment for low seam coal miners: VII. Improved knee pads. Pittsburgh, PA: U.S. Bureau of Mines.