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**PERSONAL EQUIPMENT FOR  
LOW SEAM COAL MINERS:  
VIII. IMPROVED TRACTION  
RUBBER BOOT SOLES**

Contract J0387213  
Canyon Research Group, Inc.

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83-110

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## FOREWORD

This report was prepared by Canyon Research Group, Inc., Westlake Village, California 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. Mr. William Mundorf was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period 1978 to 1982. This report was submitted by the authors in October 1982.

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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 Canyon Research Group, Inc.

### 1.1 Purpose

The purpose of this work was to develop and field test an improved slip resistant boot sole. The innovation focused on altering the tread pattern of the sole, rather than developing new materials.

### 1.2 Background

Slips and falls represent a significant source of injury in underground coal mines. In 1980, according to the Mine Safety and Health Administration (1981), slips and falls of persons accounted for 1,845 injuries, including one fatality, and 63,692 lost workdays in underground coal mining operations alone. Mine conditions which foster slips and falls include: wet, slippery, muddy, irregular bottoms; presence of oil and hydraulic fluids; inclined and undulating seam conditions; and smooth, slippery foot holds on equipment.

It has long been recognized that the critical factor determining whether a slip will occur is the coefficient of friction between the bottom of the boot and the floor surface. More precisely, two types of friction coefficients can be identified, static and dynamic. Static friction is related to the force needed to start a stationary body to move, while dynamic friction is related to the force needed to keep a moving body in motion. Typically, dynamic friction is less than static friction. Much has been written about coefficients of friction in the classical physics literature. For example, the coefficient of friction is supposed to be independent of the contact surface area, the time the body is in contact with the surface, and the mass of the body. As pointed out by Braun and Brungraber (1977), however, these "laws" do not apply to polymer materials such as those used in rubber boot soles. Pressure, standing time, temperature, humidity, time-dependence of force, and geometry of the contact area and its edges must be taken into consideration when measuring coefficients of friction.

Numerous devices have been developed to measure the slip resistance of sole materials and floor surfaces. Strandberg (1980), for example, identified 51 different slip resistance measurement devices. In almost all cases, the principle purpose of these devices has been to measure the slip resistance of various floor surfaces and various waxes/coatings applied to floors. Only as a secondary purpose have these devices been used to evaluate sole materials. The problem is that one must always measure the slip resistance of a sole and floor combination; it is impossible to measure the slip resistance of one independent of the other. A common finding can be that sole material A is more slip resistant than sole B on floor surface X, but sole B is more slip resistant than A on surface Y.

With regard to the purpose of this project, virtually all the measurement devices in use today are of limited value. First, they use very small samples of sole material, e.g., 3 in. x 3 in. This makes it very difficult to assess the relative effectiveness of various sole patterns on slip resistance. Second, the devices do not permit measurement of slip resistance while walking across sloping surfaces, as often occurs in underground mines. Brungraber (1976), and Anderson and Senne (1978) present very good reviews of the state-of-the-art and problems in slip resistance measurement. The reader is referred to these sources for a more indepth treatment of the subject.

Although the role of sole pattern as a factor in slip resistance is largely unknown, the evidence that does exist suggests that the material compound of which the sole is made is a far more important factor in determining slip resistance. Developing a new sole material, however, is a costly and time consuming activity. This project, therefore, sought a quicker, yet only partial, improvement in slip resistance by concentrating on the improvement of the sole pattern.

Most workers in underground wet mines wear steel toed rubber boots. A survey of sole tread patterns of existing rubber boots revealed numerous specific designs. The designs, however, could be grouped into two distinct categories: molded soles and calendared soles. Molded soles are constructed by pouring the liquid sole material into a mold. Different sized molds are required for each size boot. The distinguishing characteristics of molded soles are that the edge around the boot is squared off and the pattern consists of lugs and bars with square, sharp edges. The calendared sole is by far the most common type of sole on rubber mining boots. Calendared soles are made by pressing a pattern engraved on a roller into large sheets of sole material. The material is then cut to fit the boot size. The distinguishing features of the calendared sole are: (1) The edge around the boot is not squared off, but rather is rounded; (2) The sole tread pattern usually consists of relatively wide zigzag bands going laterally across the sole; and (3) the tread depth is more shallow than with molded soles.

Observations in the field and discussions with workers indicated that once the surface texture was worn off calendared soles, all that is left are three or four smooth bars across the sole. Further, the rounded edge of a calendared sole boot seems to provide little resistance to lateral slips. This condition is accentuated when walking across a slope. For these reasons, it was felt that improvements in sole tread design could be made to improve slip resistance.

### 1.3 Approach

A simple slip resistance measurement device was constructed to test off-the-shelf rubber mining boots. The four best boots, in terms of slip resistance, were compared in a mini-field test. Based on the results of the lab tests and field test, a prototype boot sole was designed and fabricated. The boots were then tested in a five month field evaluation. Attempts were made to collect slip and fall data over the five months. In addition, subjective evaluations of the prototype were collected from the participants.

#### 1.4 Organization of the Report

The report is organized around the major elements of the program. Section 2.0 describes the method and results of the mini-field test. Section 3.0 describes the prototype design. Section 4.0 describes the field test and results. Section 5.0 summarizes the conclusions and recommendations from the research.

## 2.0 MINI-FIELD TEST

### 2.1 Selection of Test Boots

A simple slip resistance measurement device patterned after that used by Ramsay and Senneck (1972) was constructed. The device used the moving sled principle for assessing coefficients of friction. The boot was placed on a slab of slate which had been thoroughly wetted with a rockdust and water solution. A vertical force held the boot in place. The force required to pull the slate slab under the boot was used as an indicator of slip resistance. The device was modified to allow the slate slab to be elevated at various angles. The boot and weight were lowered onto the inclined slab to simulate walking across a slope. This procedure was repeated to determine the largest angle of slope at which the boot would not slip. The average of 20 trials on each of the horizontal and inclined tests were used as data points. This device can only be used to measure the relative slip resistance of the various boots and cannot be directly compared to data collected using other slip resistance measurement devices. The device did serve its intended purpose and allowed a ranking of the boots tested.

Nine off-the-shelf steel toed rubber boots supplied by three manufacturers (Iron Age, Uniroyal, and Ranger) were evaluated. Four distinct sole patterns which showed the best results were selected for the mini-field test. The four boots were:

1. Iron Age Model 993 (calendared sole)
2. Uniroyal neoprene Model MB921B (molded sole)
3. Uniroyal Model MB801B (calendared sole)
4. Ranger Model 2335 (calendared sole).

The sole patterns of these boots are shown in Figure 2.1. Several manufacturers produce similar boot sole designs which tended to score together in the lab slip tests. The choice of the four specific boots took into account the lab tests, the dissimilarity in sole pattern, and the availability of the boots in the sizes needed.

### 2.2 Mini-Field Test Methodology

Twelve (12) underground workers from two mines served as participants. The participants were chosen because they did considerable walking during the course of their shift. The mines selected were both wet with slick bottom and had sloping seams (up to 20 degrees).

Each participant wore two of the four boot models, each boot for one week. A total of six (6) participants, therefore, wore each boot model. All combinations of the four boots were used, i.e., two subjects wore boots 1 and 2, two subjects wore boots 1 and 3, two subjects wore 1 and 4, two subjects wore boots 2 and 3, and so on. The order in which the boots were worn was also counterbalanced. In this way, all boots were worn by an equal number of subjects during each of the two weeks.



(a)

(b)

(c)

(d)

Figure 2.1. Sole patterns of four boots used in the mini-field test.

- (a) Uniroyal Model MB921B (molded sole).
- (b) Uniroyal Model MB801B (calendared sole).
- (c) Ranger Model 2335 (calendared sole).
- (d) Iron Age Model 993 (calendared sole).

Three types of measures were taken. (1) Subjective evaluations were collected at the end of each week. A survey form was used for this purpose. (2) Numbers of slips and falls each day were recorded by the participants on a daily record card kept in their clothes locker. This represents only an approximate indication of the actual number of slips and falls experienced since the participants had to recall their experiences over an entire shift. (3) Participants were allowed to keep one of the two pairs of boots they tested. The proportion of participants keeping each boot would indicate their overall evaluation of the boot.

### 2.3 Results of Mini-Field Test

2.3.1 Number of slips. The mean number of reported slips per day was calculated for each participant for each boot worn. Falls were so rare that they were not analyzed separately. Although participants wore two boots, the data were analyzed as a randomized groups design. The mean slips per day for each of the four boot models is as follows:

Iron Age (993)	4.97
Uniroyal (MB921B)	1.38
Uniroyal (MB801B)	3.07
Ranger (2335)	1.47

The analysis of variance, however, indicated no statistically significant differences between the means [ $F(3,20) = 1.25, p > .10$ ]. This was due to the large variance in slips between participants who wore the same boots.

2.3.2 Subjective evaluations. Each participant filled out an 11 item survey using a nine point scale (1 = not at all to 9 = a great deal). Table 2.1 presents the items, the mean response for each boot model, and the statistical significance (p) of the mean differences. Question 5, dealing with slipping while wearing the boots, indicated that participants perceived slipping less while wearing the Uniroyal MB921B neoprene molded sole boots than any of the other calendared soles. In addition, the neoprene boots were perceived as giving a more snug fit and were far and away the boots participants wanted to keep.

2.3.3 Boots to keep. The participants acted in accordance with their responses to the questionnaire. The proportion of participants who chose to keep each of the boots is as follows:

Iron Age (993)	50%
Uniroyal (MB921B)	83%
Uniroyal (MB801B)	33%
Ranger (2335)	17%

### 2.4 Conclusions from Mini-Field Test

Any conclusions from this mini-field test must be considered as tentative and somewhat speculative insofar as multiple differences existed between the boots and it is not possible to identify the causal parameter. It appears, from the subjective evaluations as well as the more objective slip data, that the Uniroyal MB921B neoprene molded sole boots were more slip resistant than the other calendared sole boots. Part of this could be

Table 2.1. Subjective Evaluations from the Mini-Field Test

ITEM	p <sup>1</sup>	IRON AGE 993	UNIROYAL MB921B	UNIROYAL MB801B	RANGER 2335
1. Were the boots comfortable to wear?	NS	4.67	6.33	3.83	3.00
2. Did your feet feel too hot?	NS	1.67	3.83	4.17	3.17
3. Did your feet feel too cold?	NS	1.00	1.33	1.83	2.67
4. Did the boots rub your feet?	NS	3.00	2.17	4.83	4.33
5. Did you slip while wearing the boots?	*	4.67	1.83	5.17	4.50
6. Were the boots heavy to wear?	**	2.17	1.17	4.67	3.67
7. Did the soles of the boots trap mud?	NS	2.50	4.67	4.00	3.33
8. Did the boots hold up to normal wear and tear?	NS	6.00	6.67	6.33	6.67
9. Were the boots too loose on your feet?	**	3.33	1.00	6.50	3.83
10. Were the boots too tight on your feet?	NS	1.00	2.83	1.67	2.00
11. Would you like to keep the boots?	**	4.50	7.67	3.50	2.17

Scale: 1 - Not at all                      4                      7 - A lot  
           2                                      5 - A moderate amount                      8  
           3 - A little                      6                      9 - A great deal

<sup>1</sup>NS - Not Significant

\* - p<.10

\*\* - p<.05

due to differences in sole materials used; however, it is believed that the deeper, sharp edged molded sole pattern was a major factor increasing slip resistance.

In addition, there seemed to be a correlation between how loosely the boot fit and perceived slips while wearing the boot. The more snug the fit, the lower the frequency of slips. Discussions with the participants indicated that when the boot is loose, especially around the ankle, the foot slips inside the boot. This "false slip" is often perceived by the person as a real slip. In trying to regain balance, the person sometimes causes a real slip to occur.

The molded sole on the Uniroyal boot is made up of a pattern of rectangular pockets. There was a tendency for these pockets to fill with mud and debris. In addition, there is no channeling of water from under the boot. This may create a hydroplane effect, in essence, holding the boot above the floor momentarily.

The mini-field test seems to suggest, therefore, that the prototype boots should have a molded sole and something to allow the wearer to tighten the boot around the foot and ankle. The sole pattern should reduce mud caking and channel water from under the boot.

### 3.0 PROTOTYPE DESIGN

Canyon Research Group, Inc. entered into contract with Iron Age Shoe Company to modify their Model 992 steel toed rubber boot according to specifications derived from the laboratory and mini-field tests. Model 992 is a 12 inch high boot with cushion insole.

Figure 3.1 shows the prototype boot developed in conjunction with Iron Age. The following design features were incorporated into the prototype design.

#### 3.1 Lace-Up Instep

A lace-up capability was added to the instep of the boot to enable users to tighten the boot around the foot. In the mini-field test, wearers with narrow feet commented that a more snug fit might reduce slips by reducing the perception of false slips inside the boot. The lace-up instep is added on to the boot, and can be simply cut off if the wearer so chooses. It was anticipated that, perhaps, one-third of the participants would choose to use the lace-up in the field test.

#### 3.2 Boot Top

Iron Age's Model 992 has a built in lace-up top. It was felt that, with the lace-up instep, a lace-up top would be cumbersome and awkward. A single strap and buckle arrangement was substituted. This modification was not intended to influence slips and falls.

#### 3.3 Sole Design

A molded sole was incorporated on the prototype to insure a sharp edge around the sole. The lug pattern was designed to present edges perpendicular to fore-aft and lateral slip vectors. In addition, the pattern does not create completely closed pockets which tend to trap mud. The more open pattern can be contrasted to the molded sole pattern in Figure 2.1(a) which is made up of a series of closed pockets. The tread depth of the sole is 6 mm.

A first generation prototype sole pattern was developed which left gaps in the outer ridge in-line with the radial channels formed by the inner lugs. The original purpose of these gaps was to serve as escape ways for water trapped under the sole. Testing of the first generation pattern, however, indicated that the outer ridge undergoes considerable wear and tear. It was felt that unless the outer ridge was joined together, the individual ridge pieces would tear off during use. The decision was made, therefore, to close the outer ridge for increased strength and durability. The field test proved this to be a wise decision.

The heel used on the prototype represents a standard heel pattern. The cost of redesigning and producing a new heel design exceeded the financial limits of the contract.

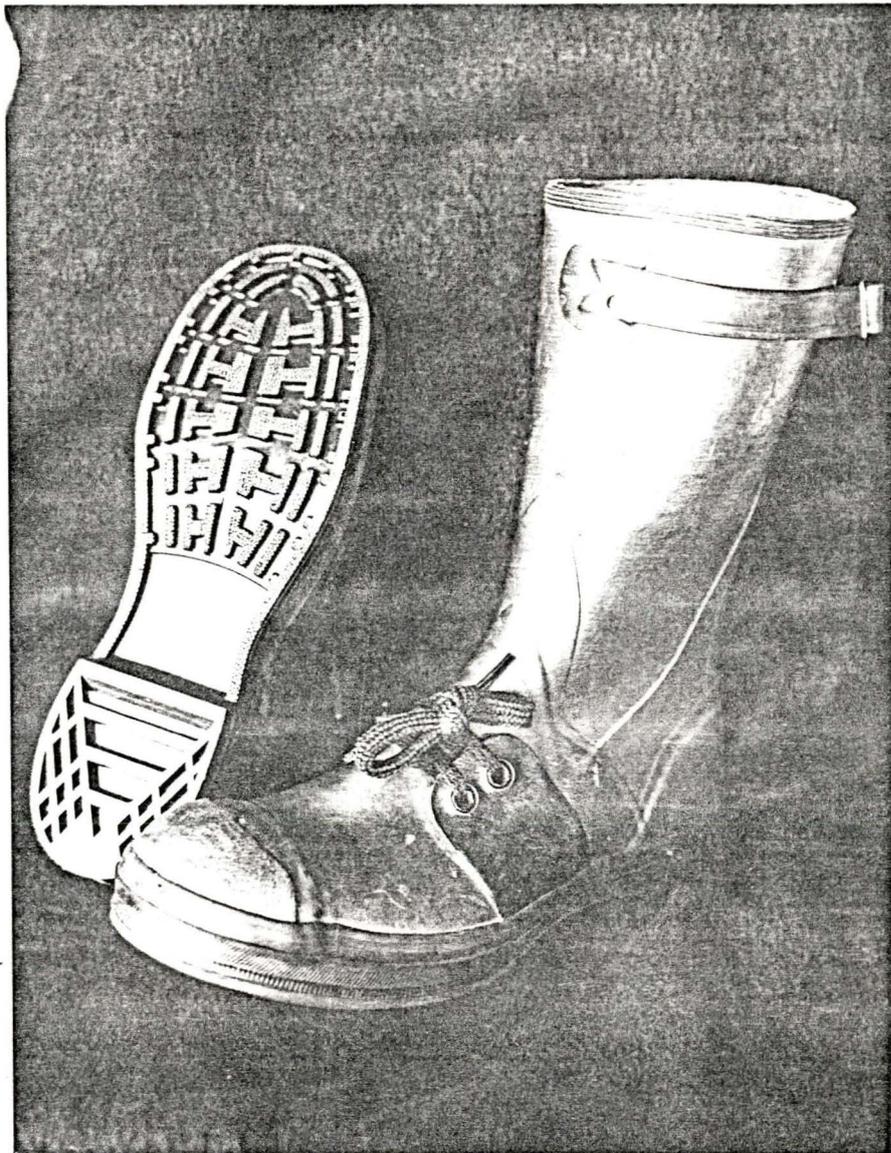


Figure 3.1. Prototype boot showing the sole pattern, lace-up instep, and strap top.

A total of 25 pair of size 9 prototype boots were manufactured for the field test. Only one boot size was used due to the costs of manufacturing sole molds for different sizes.

## 4.0 FIELD TEST

This section describes the methodology and results of the field testing of the prototype boot.

### 4.1 Methodology

4.1.1 Participants. The field test was carried out at two different mine sites. A total of 25 boots were distributed, 13 at one site, 12 at the other. Unfortunately, only 22 participants provided data during the evaluation. Two workers left the mine and took their boots with them, and one participant could not be traced. The 22 participants represented a cross section of the mining population. The following are the number of participants in various job categories:

- 7 - Equipment Operators
- 7 - Utility/Laborers
- 4 - Foremen/Supervisors
- 3 - Maintenance Personnel
- 1 - Fire Boss

4.1.2 Experimental plan. The field evaluation was carried out over a five month period. Each participant was instructed to wear the prototype boots for one month and alternate months wearing the prototype and wearing their own boots. In this way, the prototype boots were to be worn during months 1, 3, and 5, while their own boots were to be worn in months 2 and 4. Slip and fall data were collected daily and subjective evaluations were collected at the end of each month as described in the next section.

4.1.3 Data collection instruments. Each participant was given a "data packet" consisting of slip and fall data recording cards and subjective evaluation survey cards. The cards were assembled into bound packets which were to be kept in the workers' clothes basket (or lockers).

A separate slip and fall card was supplied for each week of the five month evaluation period. Each card was dated and had a space to record number of slips which did not result in falls, and number of falls for each day of the week. Each card indicated which boots were to be worn during that week, the prototype or their own. There were so few falls recorded that the number of slips without falls and the number of falls were combined for analysis.

Participants were to record the number of slips and falls at the end of each day, and at the end of the week they were to deposit the card in a collection box located in the locker room area.

After each month of slip and fall recording cards, a subjective evaluation survey card was encountered in the data packet. Participants were instructed to fill out these cards when they reached them in the packet and deposit the card in the collection box. The same evaluation survey was used each month. Table 4.1 lists the questions asked and the comparative scale used for responding.

Table 4.1. Subjective Evaluation Survey Form  
Used During Field Evaluation

Use the following scale:

- 1 - My boots MUCH better than new boots
- 2 - My boots SOMEWHAT better
- 3 - My boots and new boots ABOUT SAME
- 4 - New boots SOMEWHAT better than my boots
- 5 - New boots MUCH better

---

HOW DO THE NEW BOOTS COMPARE WITH YOUR USUAL BOOTS ON EACH OF THE FOLLOWING:

1. Snugness of fit \_\_\_\_\_
2. Traction/slip resistance \_\_\_\_\_
3. Sole wear and tear \_\_\_\_\_
4. Mud caking on sole \_\_\_\_\_
5. Comfort \_\_\_\_\_
6. Foot or calf pain \_\_\_\_\_
7. Protection from sharp rocks \_\_\_\_\_
8. Overall evaluation \_\_\_\_\_

---

1. Do you use the instep lace-ups? \_\_\_\_\_ yes \_\_\_\_\_ no

.If so, how do you like it? (Open ended response)

2. What do you like best about the new boots? (Open ended response)

3. What do you like least? (Open ended response)

4. How can the new boots be improved? (Open ended response)

After the five month field evaluation was completed, on-site interviews were conducted with the participants, a sixth subjective evaluation survey form was filled out, and tread depth data were collected.

## 4.2 Results

Results are organized into four separate categories: slips and falls, subjective evaluation, use of lace-ups, and sole wear.

4.2.1 Slips and falls. A total of 1,444 man-days are included in the data. A total of 25 subjects began the study, but only 16 supplied usable data for the slip/fall analysis. One subject terminated employment, taking the boots with him; three failed to submit data; and two subjects wore the experimental boots for an extended period but did not supply enough data on their normal boots to allow a valid comparison to be made.

Before presenting the results, it is important to indicate that we have some concern about the reliability and veracity of the slip data collected. Participants were asked to recall at the end of the day the number of slips occurring that day. The accuracy of recall is somewhat questionable. At best, the slip data represent only an estimate of the actual number experienced. In some cases, it appeared that a participant filled out several weeks worth of cards at the same time, assigning an average number of slips to each day. In such cases, the cards would show, for example, two slips each day for several weeks. It is unlikely that such consistency actually occurred. In several other cases, weeks of data were missing. To correct for missing data, the number of slips per workday was computed using only the data available.

The data analyzed, therefore, was average number of slips per workday. Each test subject gave two data points, average slips per workday while wearing the prototype boots, and average slips per workday while wearing their own boots.

A t-test for related means was used to determine if any difference existed between the average number of slips per day while wearing the experimental boots ( $x = 0.283$ ) and while wearing the miner's own boots ( $x = 0.354$ ). Although, on average, few slips per day were experienced while wearing the prototype boots, the difference was not significant ( $p > .05$ ). This is due to the great variability in the number of slips reported by the participants. In fact, half the participants reported less slips with the prototype, while half reported less slips with their own boots.

4.2.2 Subjective evaluation data. The monthly evaluation cards from the individual users were returned in diminishing numbers throughout the study; from 19 out of 25 in the first month to 4 out of 25 in the final month. Twenty-two responses were obtained during the concluding on-site interviews.

As was true of the slip and fall data, some subjects did not return a complete set of data cards for this evaluation; therefore, the responses for each subject were averaged for the cards returned. This produced one data point per subject for each evaluation question.

The mean score obtained for each question was compared to a score of 3.0, "Boots about the same" (see Table 4.1). Table 4.2 presents the means for each item and the percentage of participants rating the prototype better than their own boots, i.e., mean responses greater than 3.5.

Comfort was considered to be better for the prototype boots ( $p < .01$ ) than their own boots. In fact, only 13.6 percent of the respondents considered their own boots to be more comfortable.

The subjective evaluation of traction/slip resistance indicated that 72.7 percent of respondents preferred the prototype boots ( $p < .01$ ). Only 18.2 percent considered their own boots to have better traction and/or resistance to slips than the prototype. Almost 40 percent of the write-in responses to the question "What things did you like best about the prototype boots?" specifically mentioned traction or resistance to slipping.

The categories of sole wear and tear, and mud caking on sole were considered better for the prototype boot, with only 9.1 percent of the respondents choosing their own boots as being better.

The only question of the eight for which a higher percentage of the respondents considered their boots to be better (40.9%) than the prototype was "Protection from sharp rocks." The mean rating for this item, however, was not significantly different from 3.0.

The Overall Evaluation item was significantly different from 3.0, indicating an overall preference for the prototype boots ( $p < .01$ ). A total of 77.3 percent of the respondents rated the prototype boots as better overall than their own boots, while only 18.2 percent considered their own boots to be better.

4.2.3 Lace-ups. The data indicated that 32 percent of the participants used the lace-ups consistently; 14 percent at least tried the lace-ups, but did not use them throughout the evaluation; and 54 percent did not use the lace-ups at all. A survey of the comments supplied by some of the subjects who used the lace-ups indicated that the lace-ups kept the foot from moving around in the boot and kept the boots from pulling off in thick mud. At the final interview, however, five participants felt that the boot could be improved by removing the lace-ups. Most likely, these were people who did not use the lace-ups. The complaint regarding the lace-up was that they tended to get "caught" on things during work.

Other than the suggestion to remove the lace-ups, there did not seem to be any consistent item which was recommended for improvement.

4.2.4 Sole wear. Figure 4.1 illustrates the mean tread depth (mm) at the wear points evaluated in the study. Only the right boot was measured. Analyses were performed using a t-test to compare the mean tread depth at each point to the tread depth for new boots (6.0 mm for points on the sole, and 7.0 mm on the heel). The results indicated significant wear for all points ( $p < .01$ ), with the greatest amount of wear under the ball of the foot.

No comparable wear data were collected for the subjects' own boots.

Table 4.2. Subjective Evaluation from Field Test

ITEM	$\bar{X}$	PERCENT RATING PROTOTYPE HIGHER <sup>1</sup>
1. Comfort	3.81**	77.3
2. Traction/slip resistance	3.92**	72.7
3. Sole wear and tear	3.91**	72.7
4. Foot or calf pain	3.76**	59.1
5. Snugness of fit	3.33	54.5
6. Mud caking on sole	3.21	45.5
7. Protection from sharp rocks	3.07	27.3
8. Overall evaluation	3.91**	77.3

\*\*p<.01 comparison against 3.0

<sup>1</sup>Participants mean response exceeded 3.5.

RIGHT BOOT

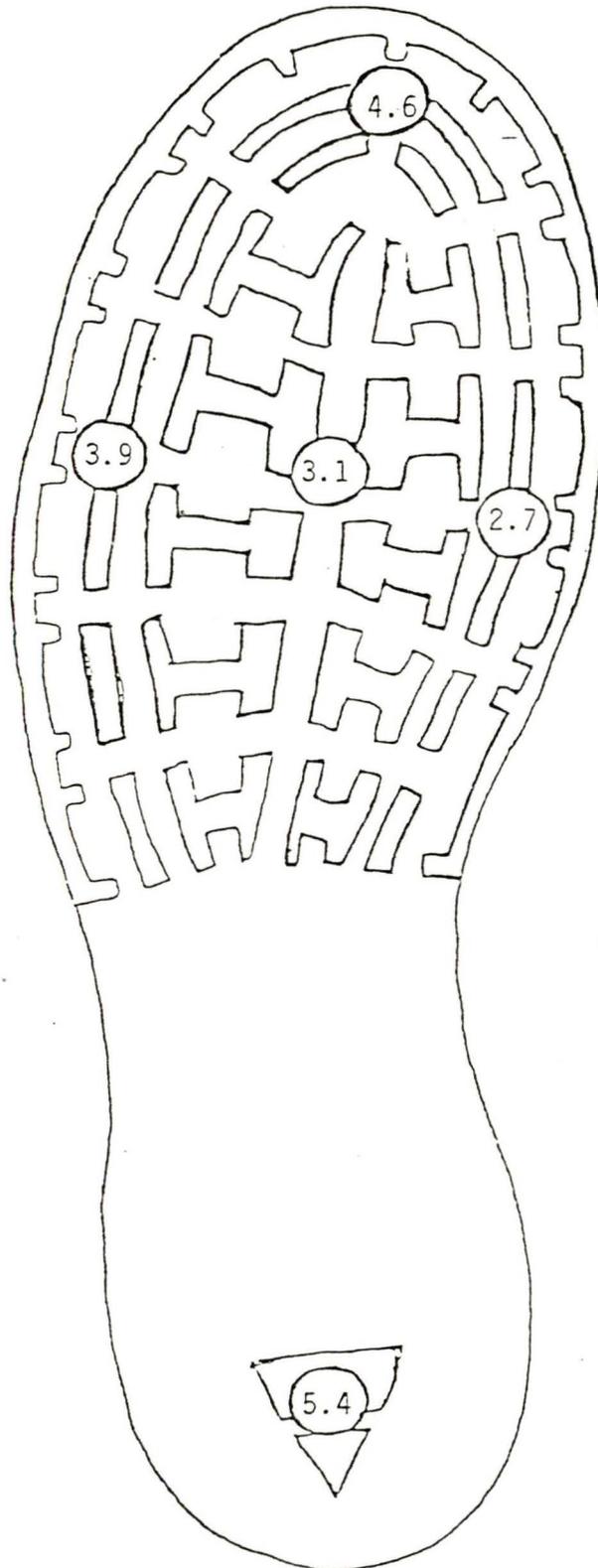


Figure 4.1. Mean tread depth (mm) for prototype boots after field test. Sole tread depth on new boots is .6.0 mm. Heel tread depth on new boots is 7.0 mm.

### 4.3 Conclusions

From the subjective evaluations, it appears that the prototype molded soles provide more traction and slip resistance than typical calendared soles currently used in underground mining. Although the objective slip and fall data were not statistically significant, they did suggest fewer slips with the prototype boot.

The instep lace-up was used by approximately one-third of the participants and seemed to serve its intended purpose of better securing the foot inside the boot. The complaint concerning catching the laces could be eliminated by a less obtrusive lace or buckle assembly.

## 5.0 SUMMARY AND RECOMMENDATIONS

Based on laboratory tests and field evaluations of off-the-shelf steel toed rubber boots, it was hypothesized that increased traction and slip resistance could be attained by redesigning the tread pattern on rubber boot soles. It was further hypothesized that securing the boot more firmly to the foot with an instep lace-up would increase stability and reduce slips and falls.

A prototype molded boot sole was developed which incorporated a deep, sharp tread pattern with edges perpendicular to lateral and fore-aft slip vectors. The pattern contained no closed "pockets" which could trap mud. It was felt that this pattern represented a significant improvement over the typical calendared soles which have shallow tread, rounded edges, and a pattern of broad bars running laterally across the sole.

The prototype sole was incorporated, along with the instep lace-up into Iron Age Model 992 rubber boots. Twenty-five pairs were manufactured and field tested at two mine sites over a five month period.

In comparison with the boots typically worn by the field test participants, the prototype was preferred by nearly three-fourths of the participants. The objective slip and fall data failed to reveal statistically significant differences between the prototype and the participants' own boots. Subjective evaluations of the boots by the participants, however, demonstrated that the prototype boots provided better slip resistance than the participants own boots. They also felt the prototype soles resisted wear and tear better than their own boot soles.

The lace-up was used by approximately one-third of the participants who felt it did stabilize their foot in the boot as expected.

The research team does not believe that the prototype sole pattern developed for this project is the optimum design; however, the team does believe that a molded sole, with sharp edges, is superior to the typical calendared soles used in underground mining. Undoubtedly, other molded sole designs would also show improved traction over calendared soles, and perhaps might even be superior to the prototype developed here.

It should also be stressed that in all likelihood, the effect of sole pattern on slips and falls is less than the effect of the compound used for manufacturing the sole.

Based on the research conducted for this project, the following recommendations are made:

1. Mines with slip and fall problems should encourage their employees to wear molded sole boots rather than calendared sole boots.
2. The Bureau of Mines should sponsor additional research directed at developing and field testing improved slip and wear resistant compounds for boot soles.

## 6.0 REFERENCES

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