A Comprehensive Survey of Material Problems Associated with Welding in the Mining Industry

FINAL REPORT
Grant No. G0166160

Submitted to:
United States Bureau of Mines
Metallurgy Division
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Colorado School of Mines

A COMPREHENSIVE SURVEY OF MATERIAL PROBLEMS ASSOCIATED WITH WELDING IN THE MINING INDUSTRY

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UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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I. Introduction

Equipment and structures for the mining, petroleum, refining and mineral processing operations all demand utilization of welded joints to perform their essential mission. Especially with the mining industry economy depending on fewer but ever increasingly large pieces of machinery (Figure 1), the capability of the maintenance department to weld-repair effectively can directly influence the amount of down time and mine efficiency. Welding metallurgy also is of major interest to those industries with concerns for safety, cost effectiveness, process and material selection, design, and weldment integrity.

The Colorado School of Mines has performed for the United States Bureau of Mines a comprehensive survey of materials problems associated with welding in the mining industry. This survey, which has involved mine visitations as well as questionnaires, has found that the mining industry is probably the most versatile of the alloy users. In a typical day the mine maintenance shop may be involved in the complete spectrum of ferrous alloys which include low carbon steels, quench and temper steels, manganese abrasion resistance alloys, tool steels, cast irons and on special occasions, stainless steel. With this complex combination of alloys being used by the mining industry to fabricate and repair their sophisticated mining equipment, the development of a more basic understanding of the metallurgy and welding procedures necessary to make alloy joints is needed. This investigation has determined, characterized and documented the present welding metallurgy and technology in the mining industry. Through a better understanding of the welding needs of the mining industry, research and development programs can be established to produce more suitable welding processes, equipment, materials and procedures. It is expected that such research and development programs will result in more economical and reliable welds on these alloy steels and in safer welding practices.

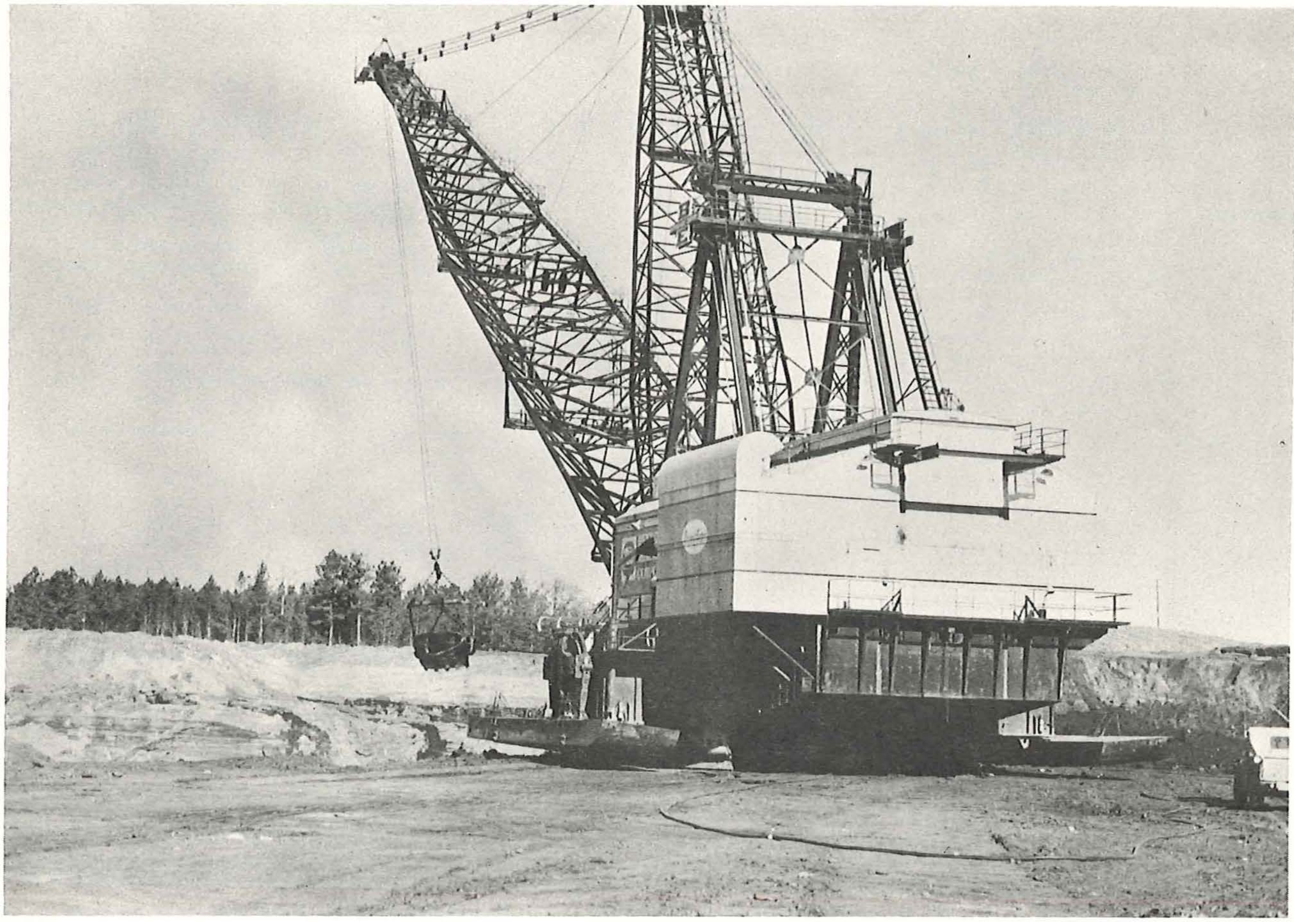


Figure 1. Mining operations are becoming more dependent on large and very expensive machines which demand effective maintenance engineering if production is not to be interrupted.

II. Mine Visitations

Visitations were made to fifteen mining operations in order to gain first hand understanding of what maintenance engineers consider their most serious welding and weldability problems. The following mines were visited:

1.	Homestake Mine	(Lead, South Dakota)
2.	Bel Aire Mine	(AMAX Coal, Gillette, Wyoming)
3.	Anaconda Mine	(Butte, Montana)
4.	Bunker Hill Mine	(Kellogg, Idaho)
5.	Kennecott Bingham	(Copperton, Utah)
6.	Consolidated Salt	(Cleveland, Ohio)
7.	Morton Salt	(Fairport, Ohio)
8.	Harbison-Walker Mine	(Eufula, Alabama)
9.	Asarco Mine	(Mascot, Tennessee)
10.	Climax Mine	(Leadville, Colorado)
11.	Henderson Mine	(Empire, Colorado)
12.	Paga Mining	(Cartersville, Georgia)
13.	New Riverside Ocher	(Cartersville, Georgia)
14.	St. Joe Minerals Corp. #28	(Viburnum, Missouri)
15.	Reynolds Mining Corp.	(Bauxite, Arkansas)

The on site metal forming and joining capabilities of these mines are very impressive and their maintenance engineers were informative. The questionnaire forms used for these initial visitations can be found as Appendix A. Also small welding shops in mining towns as well as welding shops on military bases where high quench and temper steel are being welded were visited.

Mine welding questionnaires were also sent to over two hundred and twenty operating mines in the United States. These mine operations cover the full spectrum of types and sizes of mines. A copy of the letter and questionnaire is shown in Appendix B. A 6.6% response to the questionnaire was received and the results will be found throughout this report. The questionnaire in Appendix B also gives the quantitative results of this survey.

We have also discussed with both welding equipment and mine equipment manufacturers their efforts to solve the concerns of the mine maintenance engineers.

III. Categories of Welding Practice for Mining Industry

Welding practice can be best classified into three categories. In order of increasing welding difficulty, these classifications are:

a. Mine Maintenance Shop Welding

The welding techniques in the mine maintenance shop are usually based on proper welding procedures since these facilities have the ability to do good edge preparations and proper fixturing (Figure 2). Welding in the mine maintenance shop represents 68% of the welding performed for the mining operation. Mine maintenance shops are utilizing manual (shielded metal arc welding), automatic (submerged arc welding) and semi-automatic (gas metal arc welding) equipment. It is also convenient to use preheat and postheat treatment in these shops. The ability of these maintenance shops to fabricate and repair the large sections of steel on mining equipment is most impressive. Figures 3 and 4 illustrate the complete rebuilding of a mining vehicle in a mine maintenance shop.

b. Welding in Open Pit Mines

Above ground welding of mining equipment and structures is a very common practice. These welds are made with the serious welding difficulties of moisture, poor fixturing, out of position, poor edge preparation and tremendous time constraints. Effective maintenance welding takes good planning of materials and personnel in order to keep mine production at an optimum. An example of the materials and process selections that must be made is seen in the different approaches to abrasion control. Some mines use high manganese steel cast liner plates which are plug and lap welded onto the abrasion surfaces of a shovel (Figure 5), while other maintenance engineers use weld overlay clad patterns (Figure 6) of abrasion resistance alloys to give better service life. The selection of techniques for abrasion control will depend on size of equipment, labor

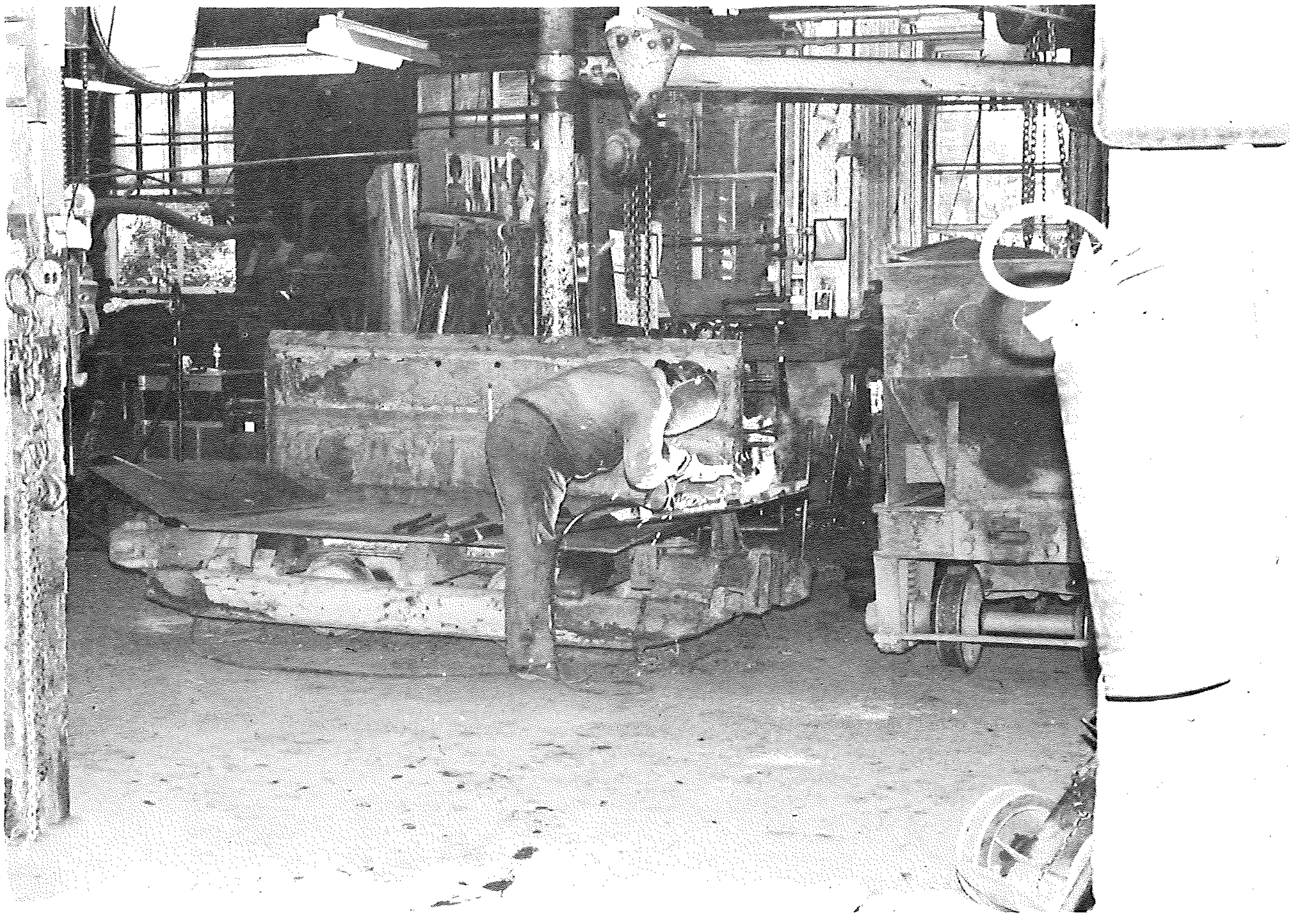


Figure 2. Welding in a surface mine maintenance shop has the advantage of facilities which can allow for utilization of good welding procedures.

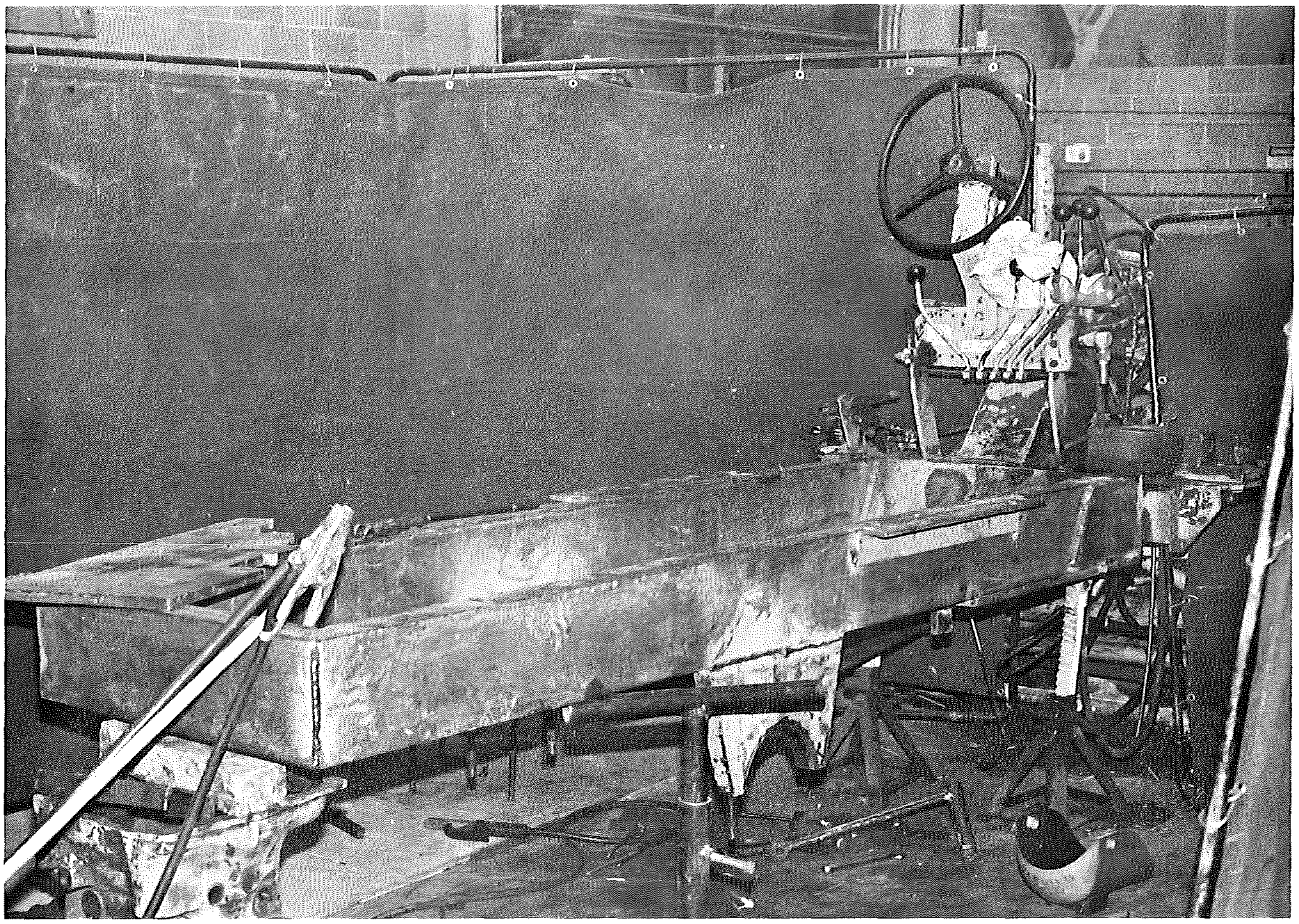


Figure 3. The complete rebuilding of a mine vehicle in the mine maintenance shop.

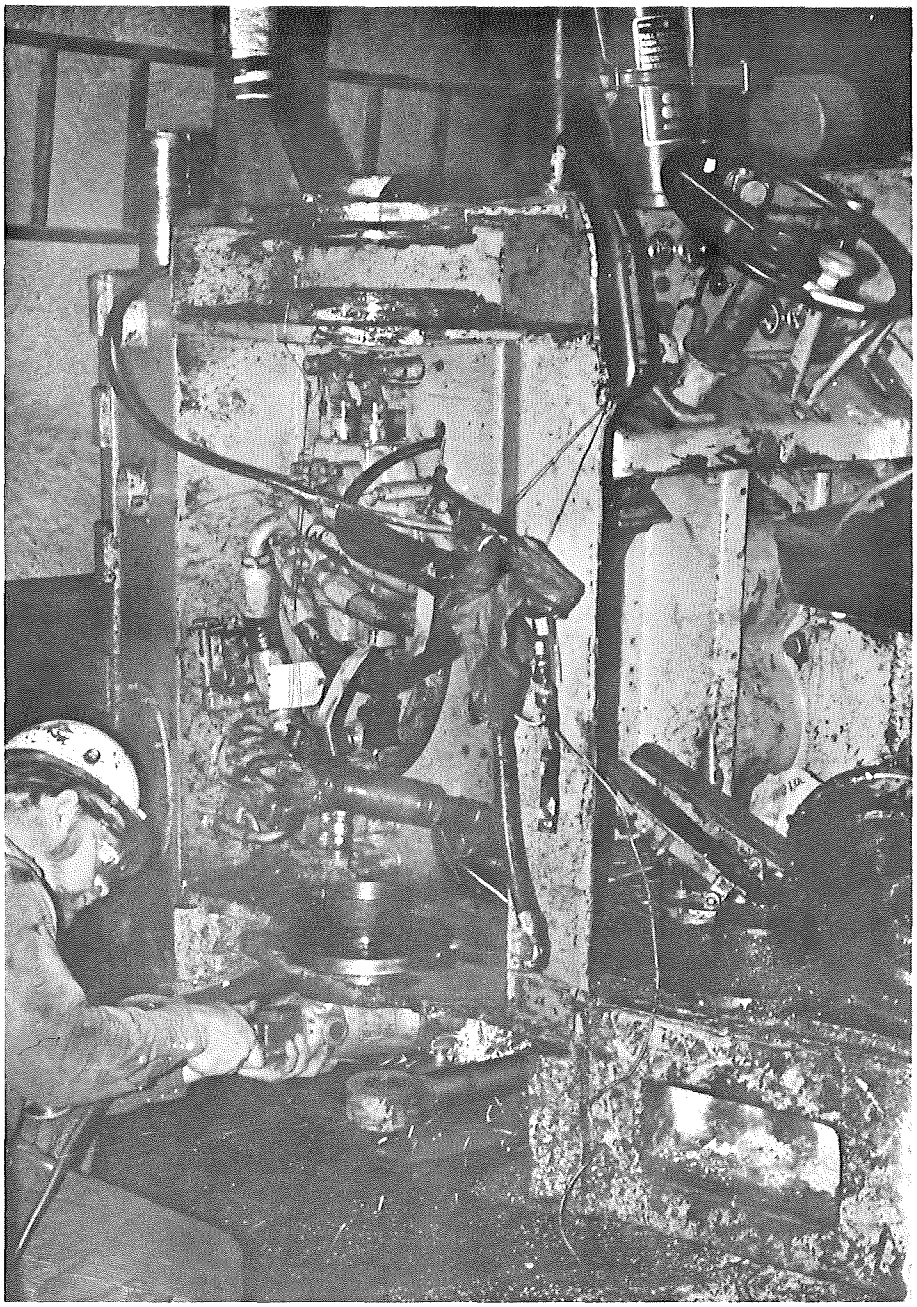


Figure 4. Edge preparation for weld repair of large mine vehicle.

Figure 5. High manganese steel cast liner plates which are plug and lap welded onto the surface of a shovel in open pit mine.

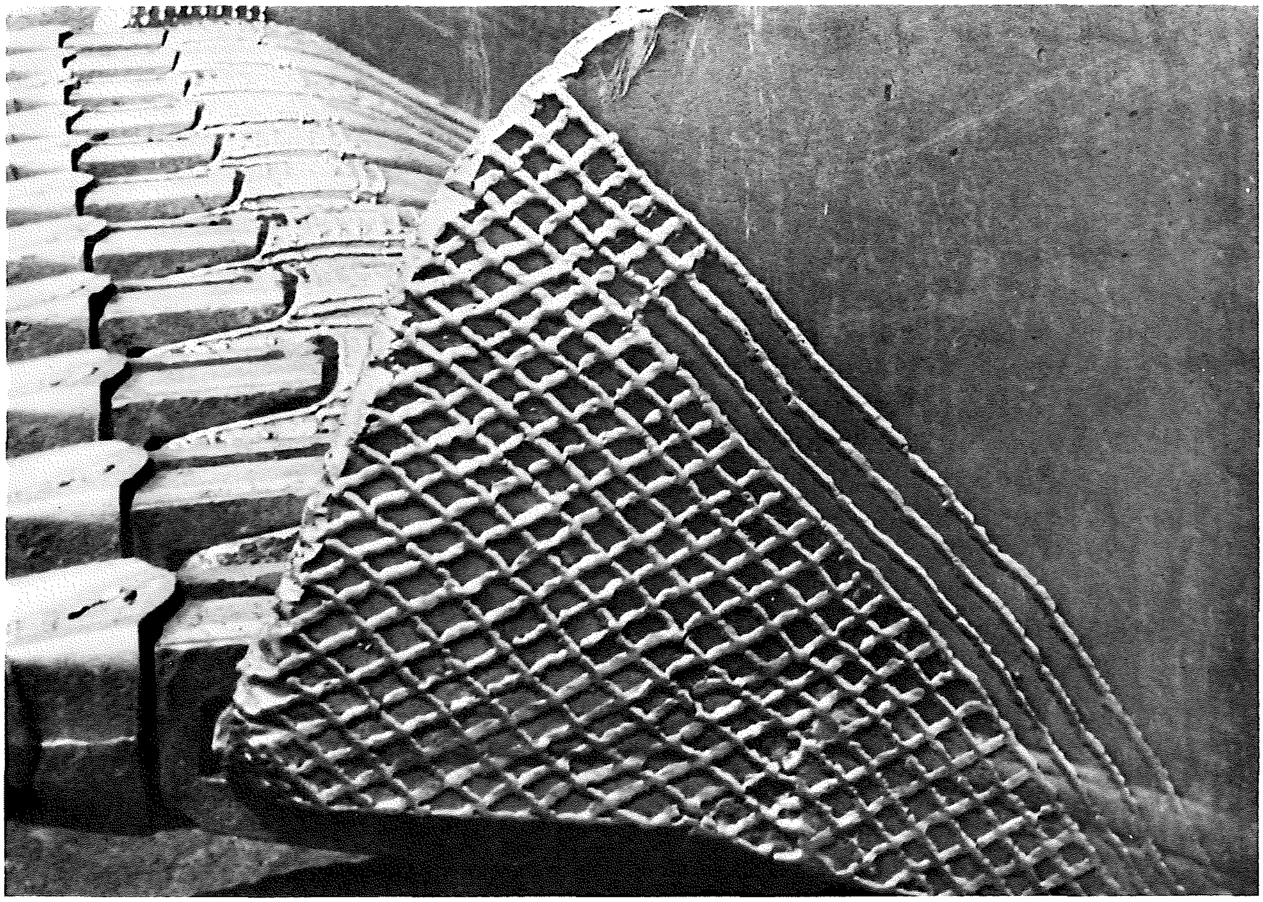


Figure 6. Weld overlay cladding of abrasion resistant alloy welded onto the shovel in open pit mine. Notice the specific clad pattern selected for this coal mining application.

and material costs. Most of the larger mines have made some attempt to evaluate the different techniques and materials.

The electrode selection is very critical for surface (field) welding, especially with the increase in the use of alloy steels which are usually very susceptible to hydrogen damage. It is very difficult to keep electrodes dry and proper preheat is most often not attempted. It is most likely that underbead cracking is occurring in a large fraction of these weldments.

c. Underground Welding

Welding underground is usually kept to a minimum with every effort made to do more joining operations in the surface maintenance shop. A certain number of welds must be made underground and under the most severe conditions. Mine welding represents 24% of welding done by a mining operation. The welding is most often out of position, and on unclean and possibly wet surfaces. The welder is operating in a hot, humid and poorly lighted environment (Figure 7). Figure 8 shows the layout of an underground mine welding shop. Care should be taken in selecting low alloy steel (typical structural steels) with carbon equivalents much below 0.40% to reduce the concern for hydrogen cracking.

d. Welding Contract Out

There is a certain fraction (7.5%) of the welding requirements for the mining industry that are sent out to welding shops which are not directly associated with mines. Smaller mines are more dependent on the welding talent of local welding shops. Larger mines usually send out the more complex welding involving difficult alloys. Welding shops in the new mining districts being developed for coal and uranium mining are presently extremely busy.

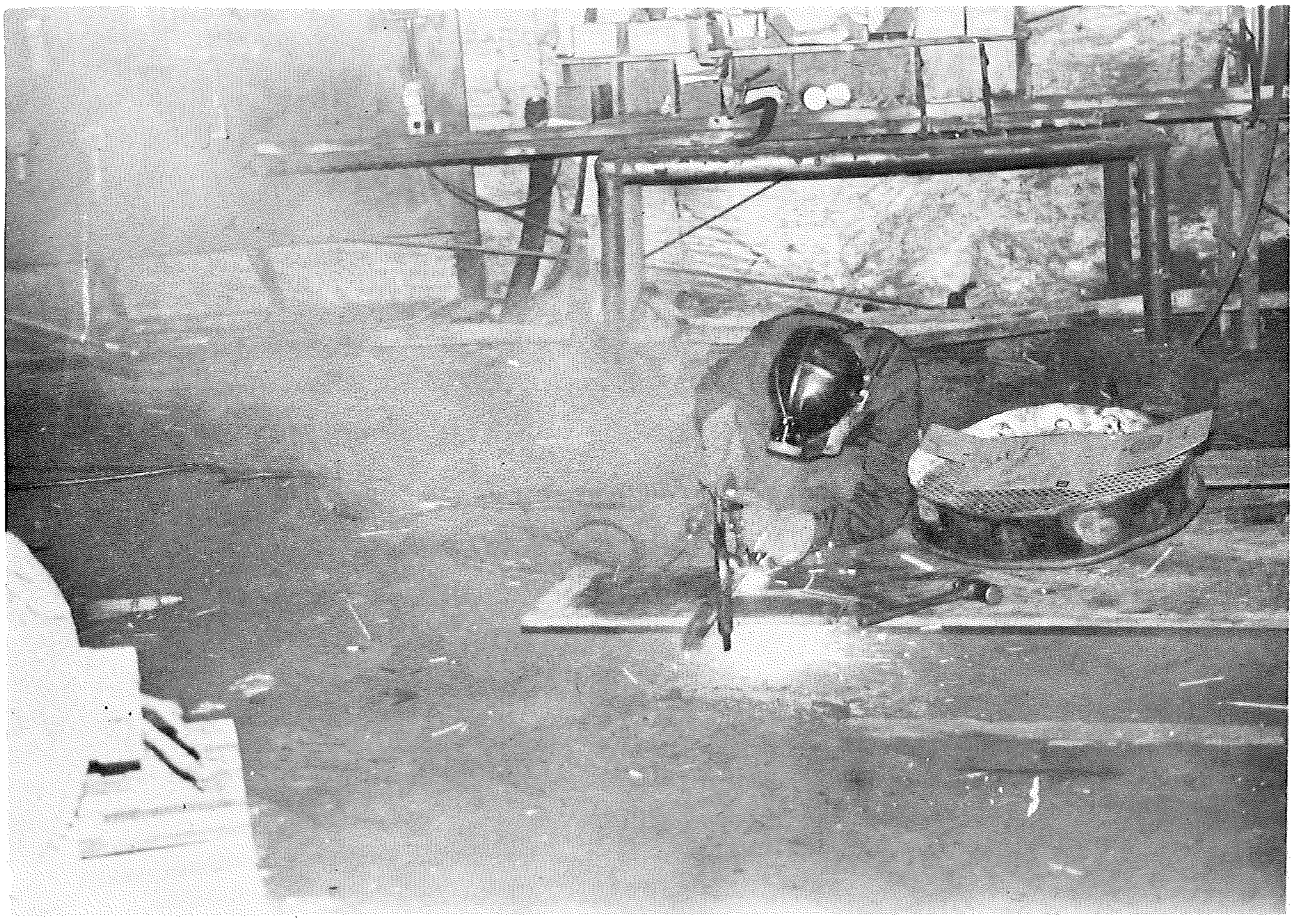


Figure 7. Underground welding is usually performed in hot, humid and poorly lighted environment.

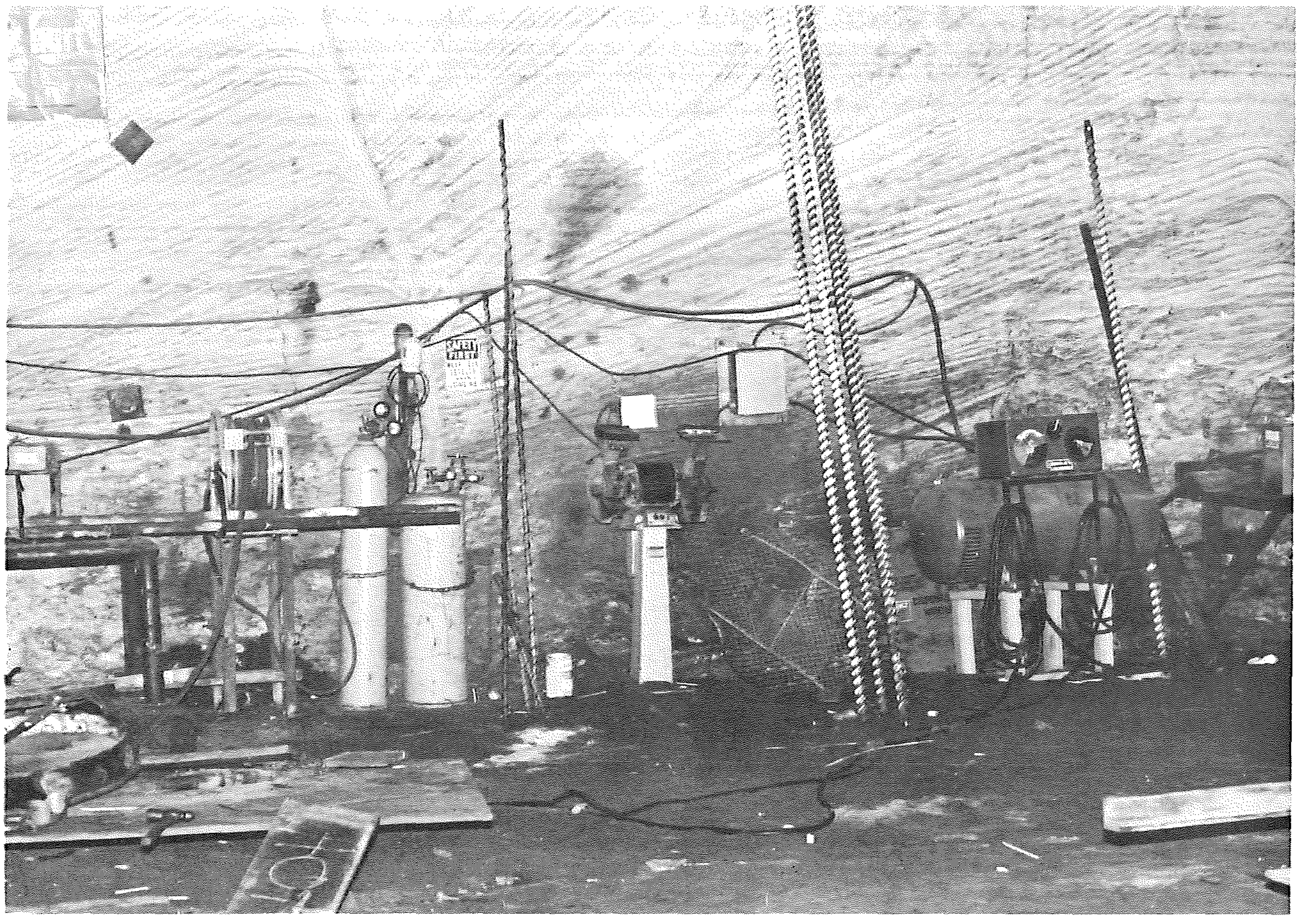


Figure 8. Underground mine welding facility which is equipped for cutting, edge preparation and welding.

IV. Welding Processes for Mine Maintenance Welding

Shielded Metal Arc (Covered Electrode) Welding

The survey indicates that approximately 72% of all welding for mine maintenance is performed with shielded metal arc (SMA) welding. Shielded metal arc is used nearly exclusively in the mine since it involves less equipment than the gas-arc processes (Figure 9). Both low hydrogen and low carbon steel electrodes are used. There now appears to be specific commercial brands preferred by the mining industry. How an electrode brand is selected at a given mine usually depends on the size of the mining operation. If the mining operation is large enough to have a purchasing department, large orders for electrodes usually go out for bid. Large mine maintenance shops often have a wide variety of brands of the same AWS electrode designation. In smaller mining operations the brand of electrode often is purchased based on good mine-supplier relationships since welding expendables and equipment suppliers are often the source of experience to solve difficult welding problems. Some of the electrodes seen at the mine maintenance shops are:

6010 Airproduct, Hobart

7018 Airproduct, Hobart

Eutectic 680 Austenitic electrode

Haynes Stellite Alloy #6

High Nickel rod for cast iron

9018 (with 7018 root pass)

312 Stainless steel rod

7011 for mild steel

7016 for mild steel

8018 for alloy steel

2109 for aluminum

2101 for aluminum

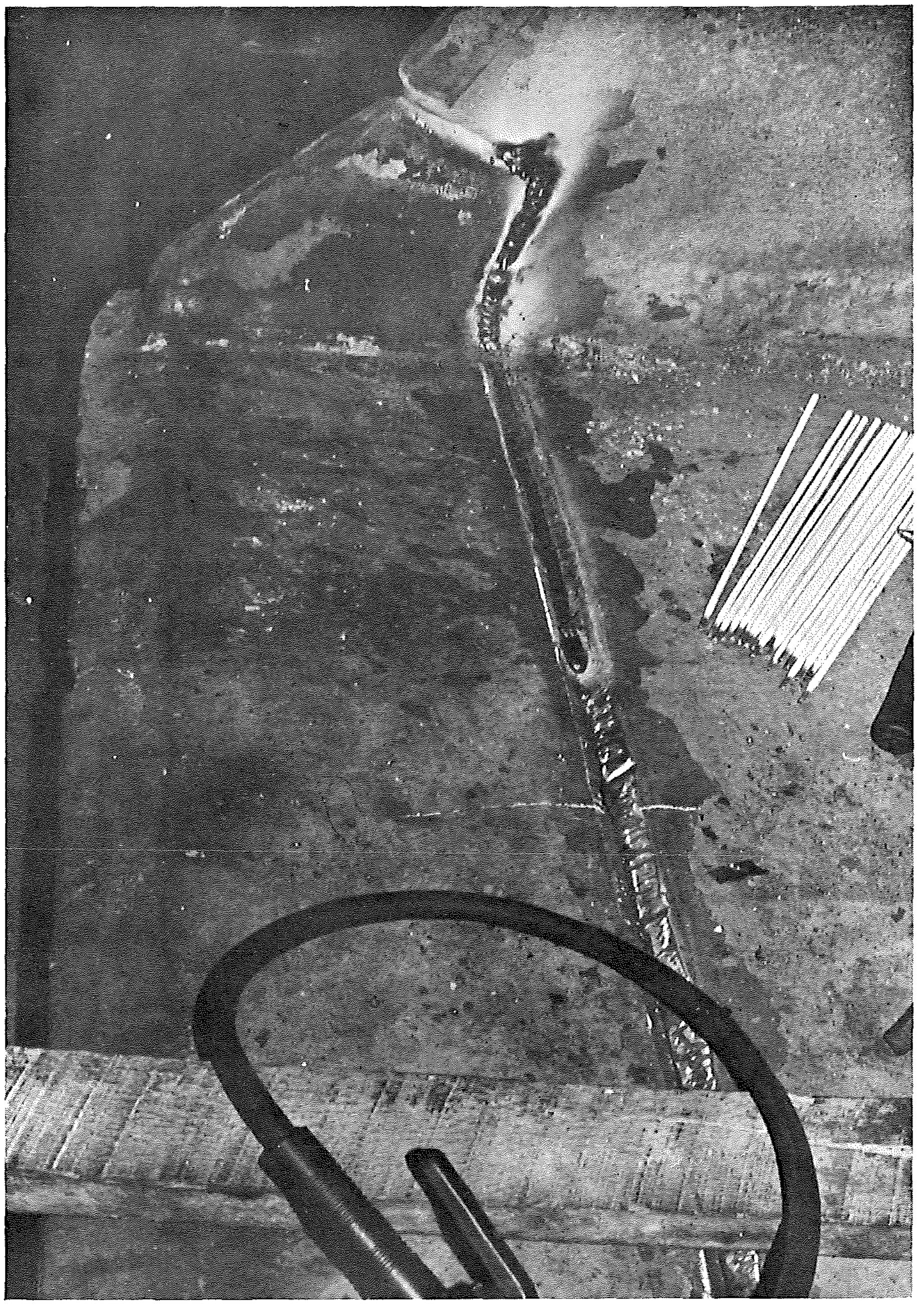


Figure 9. Shielded metal arc (SMA) welding of a shovel tip.

The most common overall electrode was the E 7018 electrode, common to all mines visited.

Gas Metal Arc (GMA) Welding

The survey indicates that approximately 17% of all welding for mine maintenance is performed with semiautomatic gas metal arc welding process. Nearly all this welding is done in the maintenance shop (Figure 10). There is a strong trend, especially in the larger mine operations, to convert to GMA welding. Many maintenance shops have built arrangements in their welding areas for easy access to wire feeding equipment and gas. Gas metal arc welding has major advantages over covered electrode welding since it takes a less experienced welder to use this process and is a much faster process. A variety of welding gas (mainly CO_2 and Ar -2% O_2) is being used. Pure argon, usually used just for gas tungsten arc welding was found in use in a few maintenance shops. The role of gas mixture for gas metal arc welding was not completely understood at all mine maintenance shops visited. The economics of CO_2 welding is explored at many mining operations. 7018 wire is very common and flux core wire is also being used. The gas metal arc welding of rail for the mine is seen in Figure 10.

There appears to be two major hinderances to this movement to wire processes. First, the present gas metal arc welding processes use constant potential power supplies while the covered electrode (SMA) welding is done with a constant current welding power supply. Thus the transition requires capital expenditures and the phasing out of usually functional welding equipment. Secondly, gas metal arc wire welding does not require the degree of experience and training as the covered electrode welding. As a result many of the older experienced welders are concerned about the status of their employment and discourage the use of the wire process.

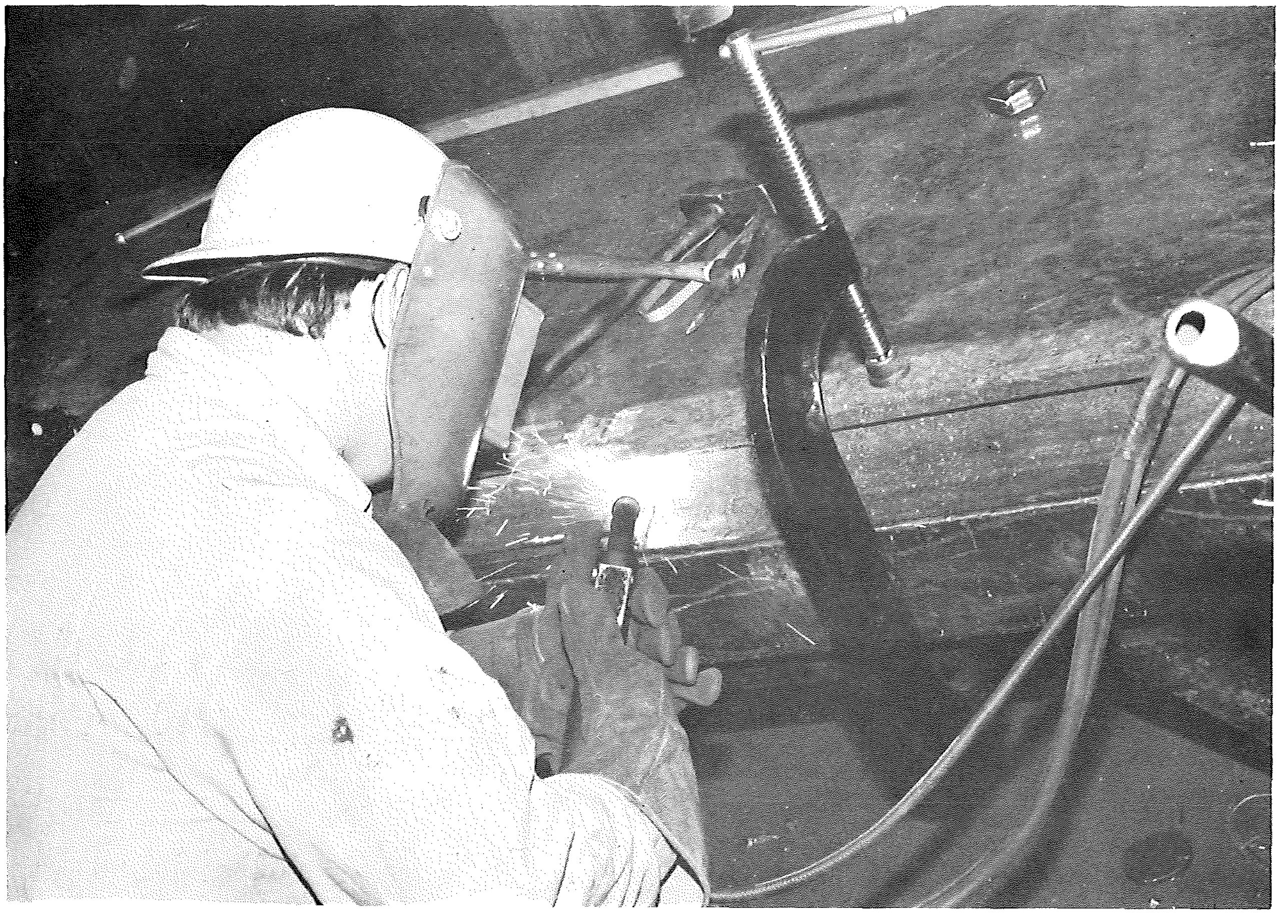


Figure 10. Gas metal arc (GMA) welding of rail section for mine use.

Submerged Arc Welding

Approximately 1% of the welding being performed at mining operations is submerged automatic arc welding. This flux-wire process is being used to build up or deposit new metal on worn parts, usually shafts and railroad wheels for mine trains. The setup time is usually long and procedures more involved but the metal being deposited by this process is impressive. It takes very careful welding to watch the temperature of the part during welding and the cooling rate after welding. Figure 11 illustrates the submerged arc repair welding of railroad wheels.

Oxy-acetylene Welding and Cutting

Oxy-acetylene welding involves about 10% of the total mine welding. Oxy-acetylene cutting is the major approach to steel cutting and edge preparation for welding. It is a very convenient source of heat for difficult to reach places in a mine. Figure 12 shows an advance multi-torch cutting system cutting thick steel plate in a mine maintenance shop. Oxy-acetylene torch is usually the source of heat for most pre-heating operations.

Welding Machines

Welding machine requirements in the surface mine maintenance shop are no different than in any fabrication shop. There is an apparent transition from constant current to constant potential welding power supplies as wire welding processes become more acceptable in mine maintenance shops. One of the hinderances to changing to wire processes is the fact that it is necessary to purchase a different power supply.

Underground welding requires more from the welding machines. The welding machines are handled roughly and are in a very dirty, wet and corrosive environment. Figures 13, 14, and 15 show types and conditions of welding machines

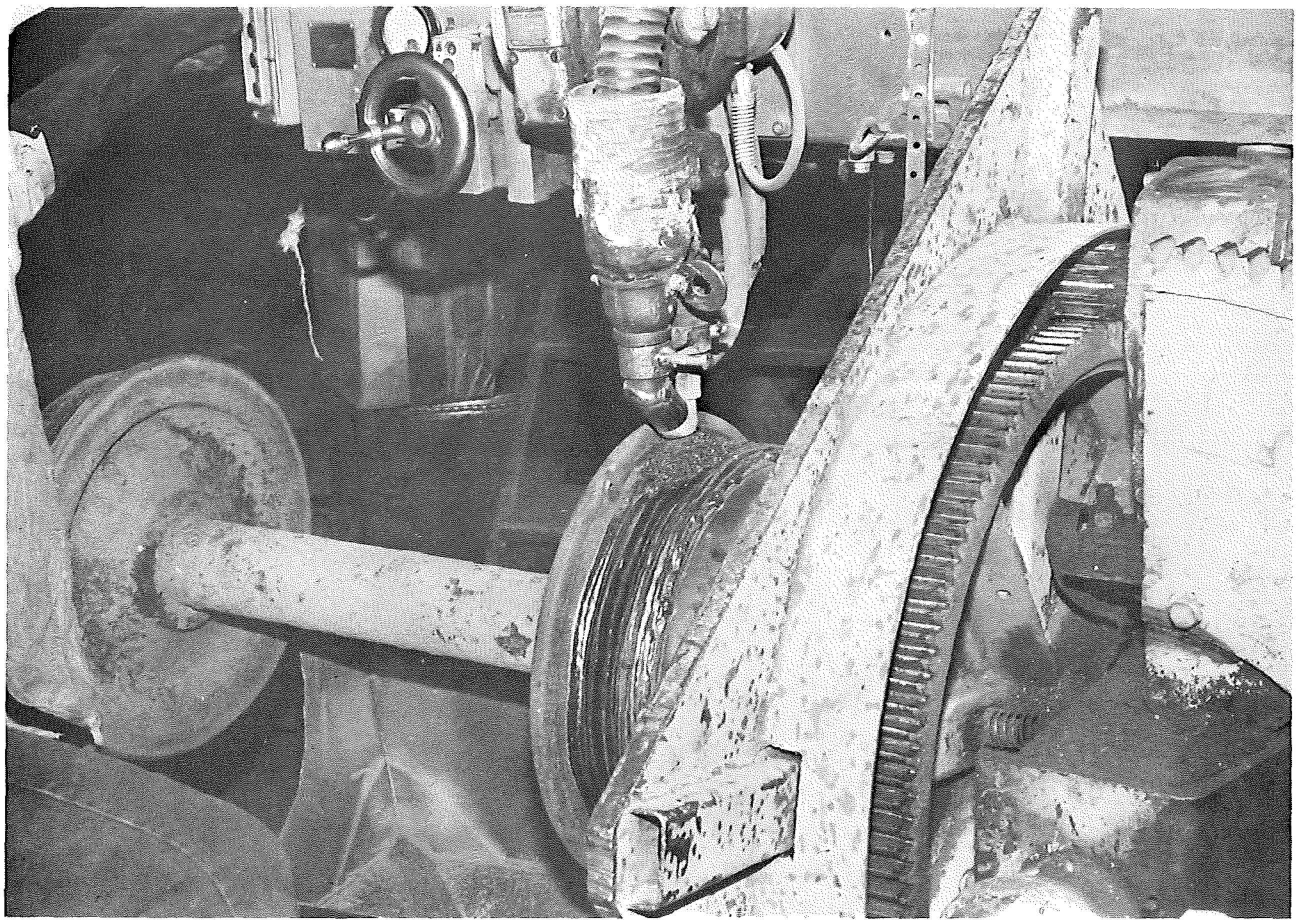


Figure 11. Submerged arc welding repair of worn railroad wheels. A practice not accepted by the Dept. of Transportation for the major rail systems but for the lighter trains used by the mining industry, the practice has proven both safe and economical.

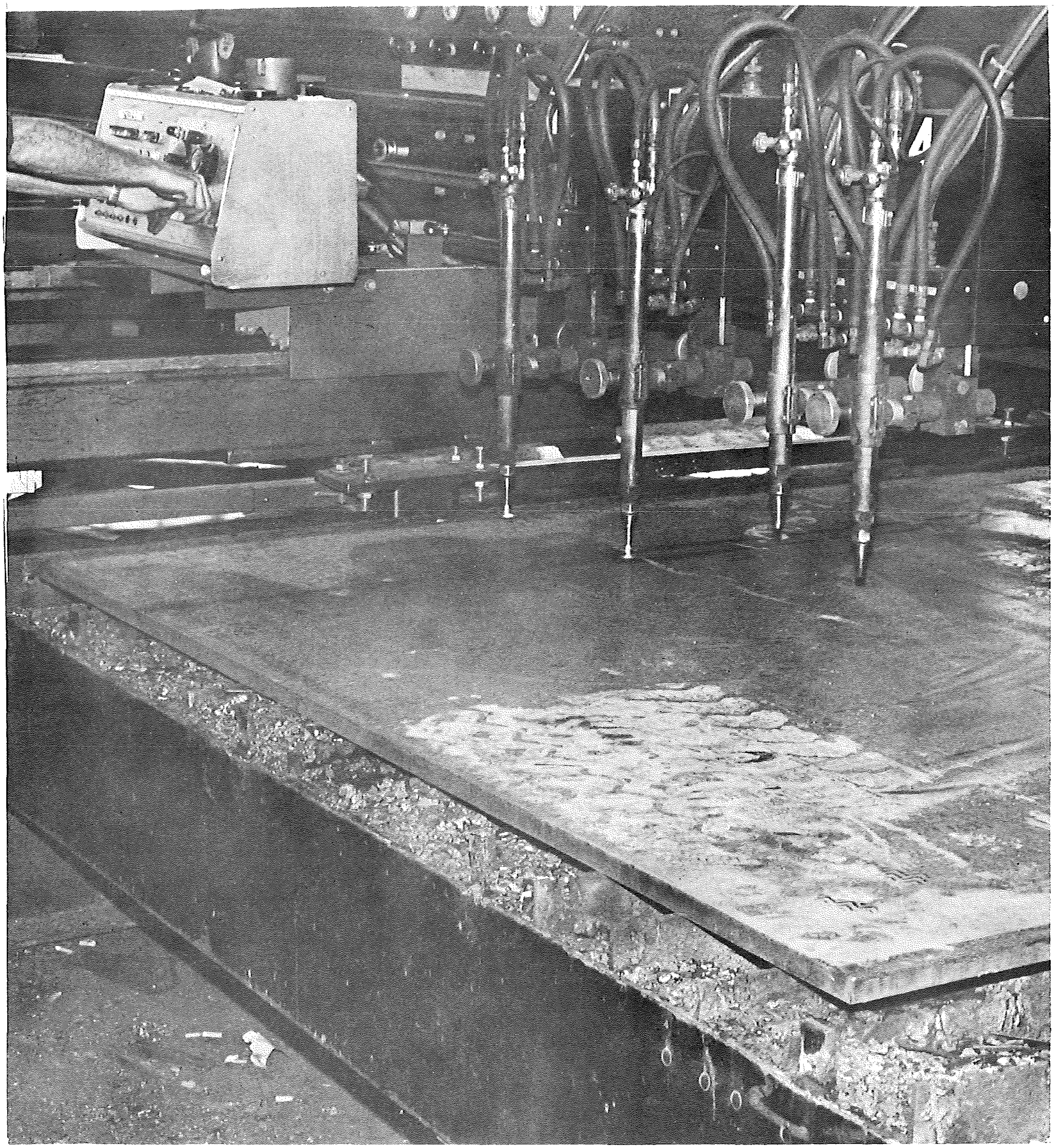


Figure 12. Multi-oxyacetylene torch automatic cutting system being used in a mine maintenance shop for cutting thick steel plate pieces for fabrication.

Figure 13. D. C. rectifier welding power supply being used for underground welding. Notice the amount of corrosion on the power supply.

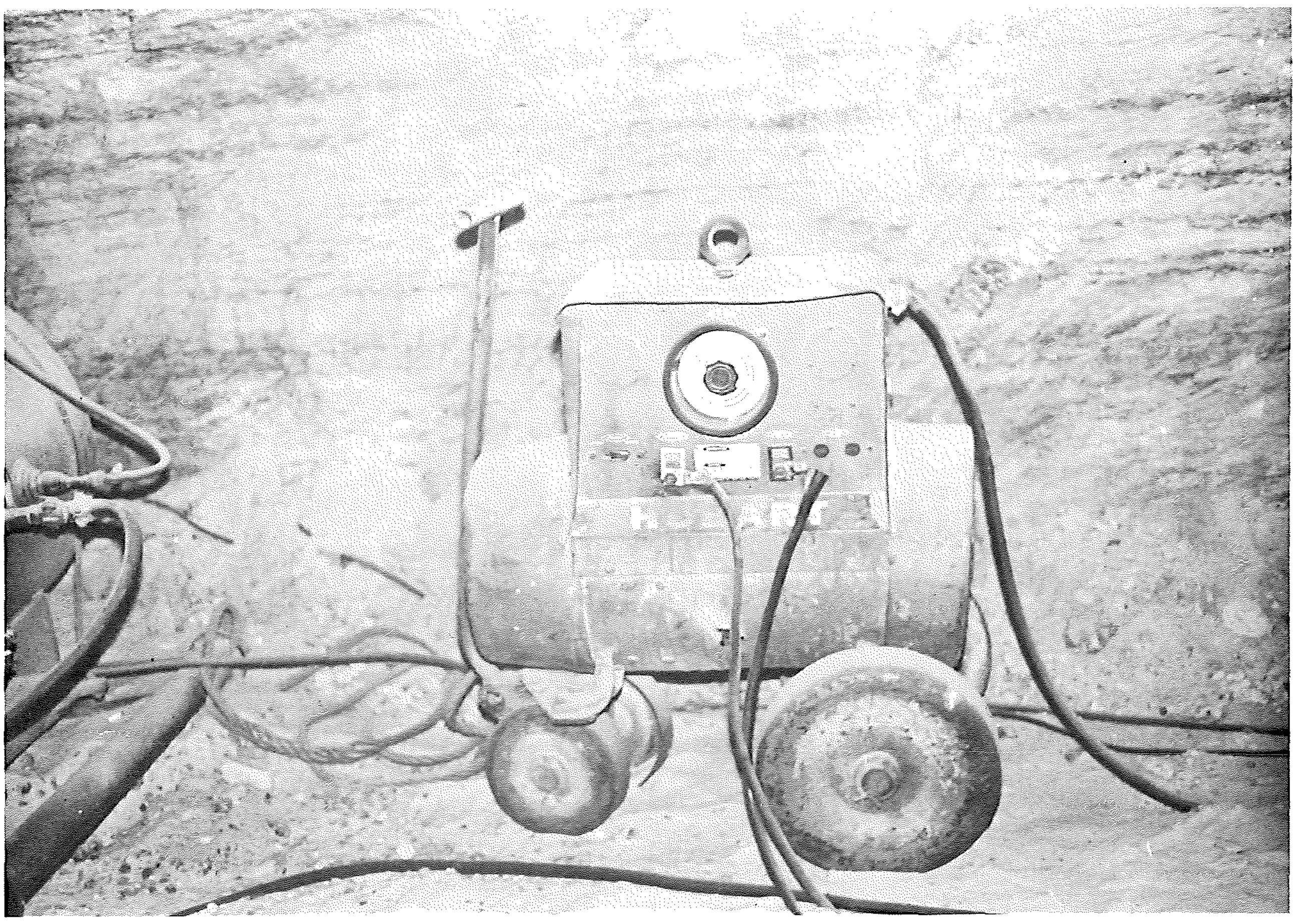


Figure 14. D.C. motor generator welding power supply being used for underground welding.

Figure 15. Diesel driven motor generator welding power supply being used for underground welding.

found underground. Figure 13 has a D.C. rectifier power supply which requires a power distribution system underground. Figure 14 shows a D.C. motor generator welding supply which is more mobile but also requires a power distribution system. A very convenient arrangement is the diesel driven motor generator welding power supply that is shown in Figure 15.

Welding power supply manufacturers could definitely design a better package to reduce damage and corrosion problems. Manufacturers should first inquire about this market for our investigation was inconclusive as to whether the mining companies would pay the higher price for a superior welding supply.

V. Specific Types of Welding in the Mining Industry

Although all alloy systems are integrated into the overall mine operations, the major portion of the welding is on mild and low alloy steels. If the mine maintenance shop is also responsible for concentration operations, it also performs stainless steel welding. Table I lists the various alloy types and percentage of the total welding each alloy type involves.

Table I Percentage of Welding for Various Alloy Systems

Type of Welding	Percent (%)
Low carbon steel	61
Alloy steel	23
Hard facing	6
Cast Irons	5
Stainless Steel	4
Aluminum	1

Mine maintenance shops are involved in production welding of specific components of mine machinery, large section fabrication, assembly of new mine machinery, repair welding of mining machinery, weld build-up and hardfacing.

A. Production Welding

Production welding involves the fabrication of large numbers of identical components for the mining operation. In order to maintain an uninterrupted mining operation, competent mine maintenance departments have available in inventory on site those components or sections of the mining machinery that have a limited service life (Figure 16). Knowing which components or sections are subject to frequent repair, the mine maintenance shop will maintain a continuous production operation. Fabrication of such components should allow the welding engineer time to establish proper design and welding procedures to assist in better weld economy. The on site production type welding of replacement components is usually a common practice of the larger mine operations. Small mining operations most likely will use a dependable supplier or local fabrication shop for this service. Economical production welding for a given mining operation depends on the size of the operation or number of parts needed annually and difficulty of procuring such parts. It is anticipated that automatic and semiautomatic equipment will move into service for such operations.

B. Large Section Welding

Both surface and underground structures require good engineering design and welding procedures. Out of all the welding done by mine welders large section and structural welding is most consistent with the typical training of welders outside of the mining industry. Most of the structural welding uses mild steel (A36 or AISI 1020 type steel). Low carbon steel welding involves over 60% of the mine welding. It is expected that new HSLA steel will slowly move into structural welding to reduce size and weight of structural section for easier handling underground. The use of new alloys has always been a slow process in the mining industry since utilization of a given material is based mainly on the confidence of experience rather than engineering data.

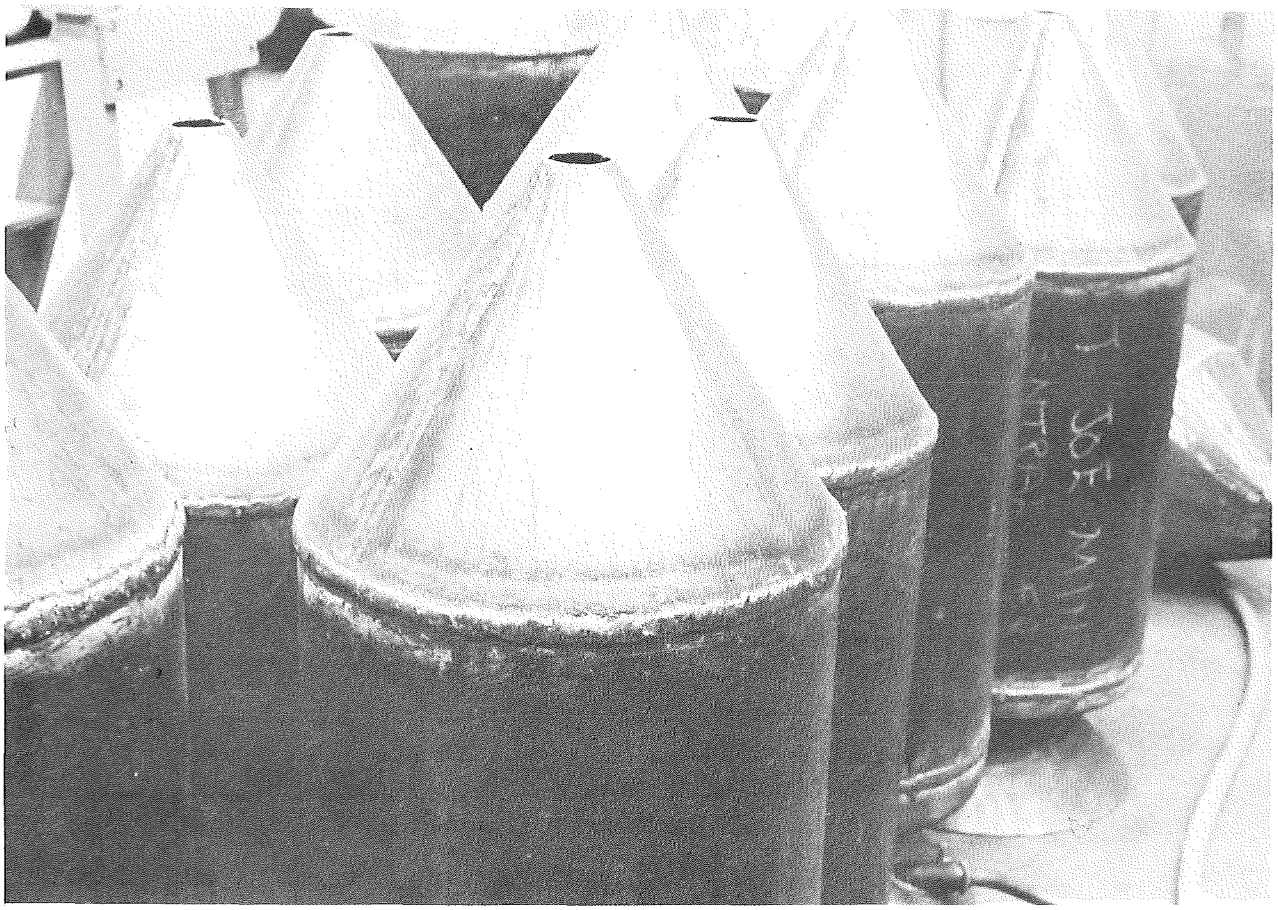


Figure 16. Production welding of essential components for the mining operation in order to maintain an inventory to guarantee an uninterrupted mining operation.

Pipe welding is also being performed by some mine maintenance departments.

C. Assembly of New Mine Machinery

The size of modern mining equipment requires this machinery to be assembled at the mining site. Figure 17 illustrates the assembly of a large mining truck bed in a maintenance shop at a new open pit coal mine. Larger machinery is also being used underground which has required the assembly after sections of the equipment have been lowered. Good communication between equipment manufacturer and mine maintenance shop is necessary if the proper welding procedures are implemented to assemble their equipment. It was apparent that excellent technical assistance from the manufacturer is available if specified as part of the purchase agreement. On our mine tours we met very competent personnel from manufacturers who were assisting in proper assembly and redesign of their equipment. It would be of assistance to the mine maintenance department if the engineering drawings of mining equipment also indicated the materials involved and suggested proper welding procedure.

D. Repair welding of mining machinery

Mining equipment is used in heavy service causing continual deformation and abrasion in many parts demanding quick and proper weld repair to maintain optimum mining efficiency. Figure 18 illustrates the common replacement of shovel bucket lip by cutting out worn lip and installing a new high alloy lip by welding. Figure 19 illustrates a replacement of the bushing on a bucket by quickly cutting out the old bushing and installing the already prepared bushing part and welding. Figure 20 shows a similar repair on a large bucket and illustrates the complex cutting, filling and welding on alloy steel, which a maintenance engineer must solve in a very short down time period in order to be effective. Figure 21 illustrates the continual redesigning of mining equipment necessary to increase the service life. In this figure a section is cut

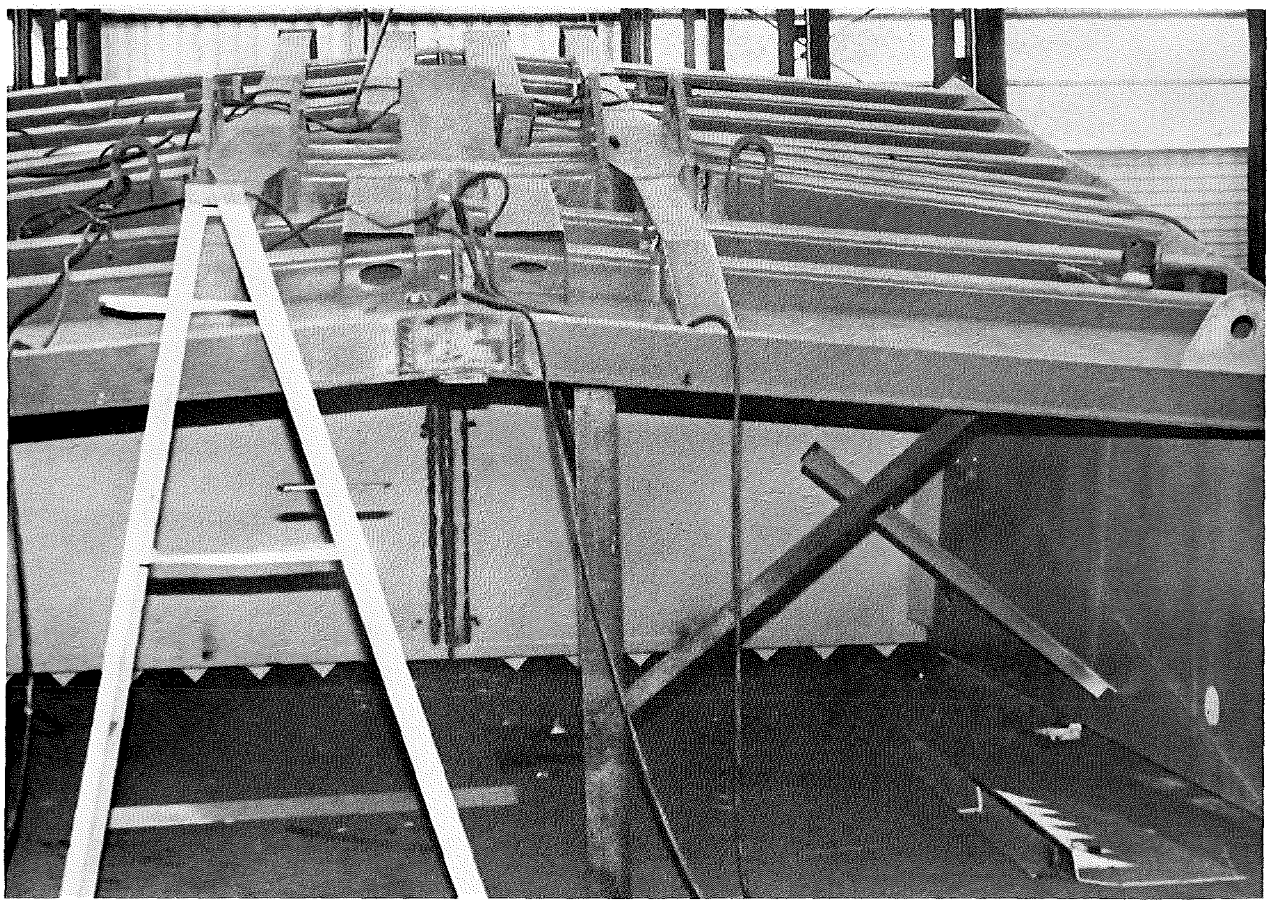


Figure 17. The weld assembly of a large mining truck bed for use in a new coal mine in Wyoming. Due to the size of these vehicles it is necessary to assemble them at the mine site. This requires large capital expenditures by the mining operation in order to have the proper fabrication facilities to handle these large parts.

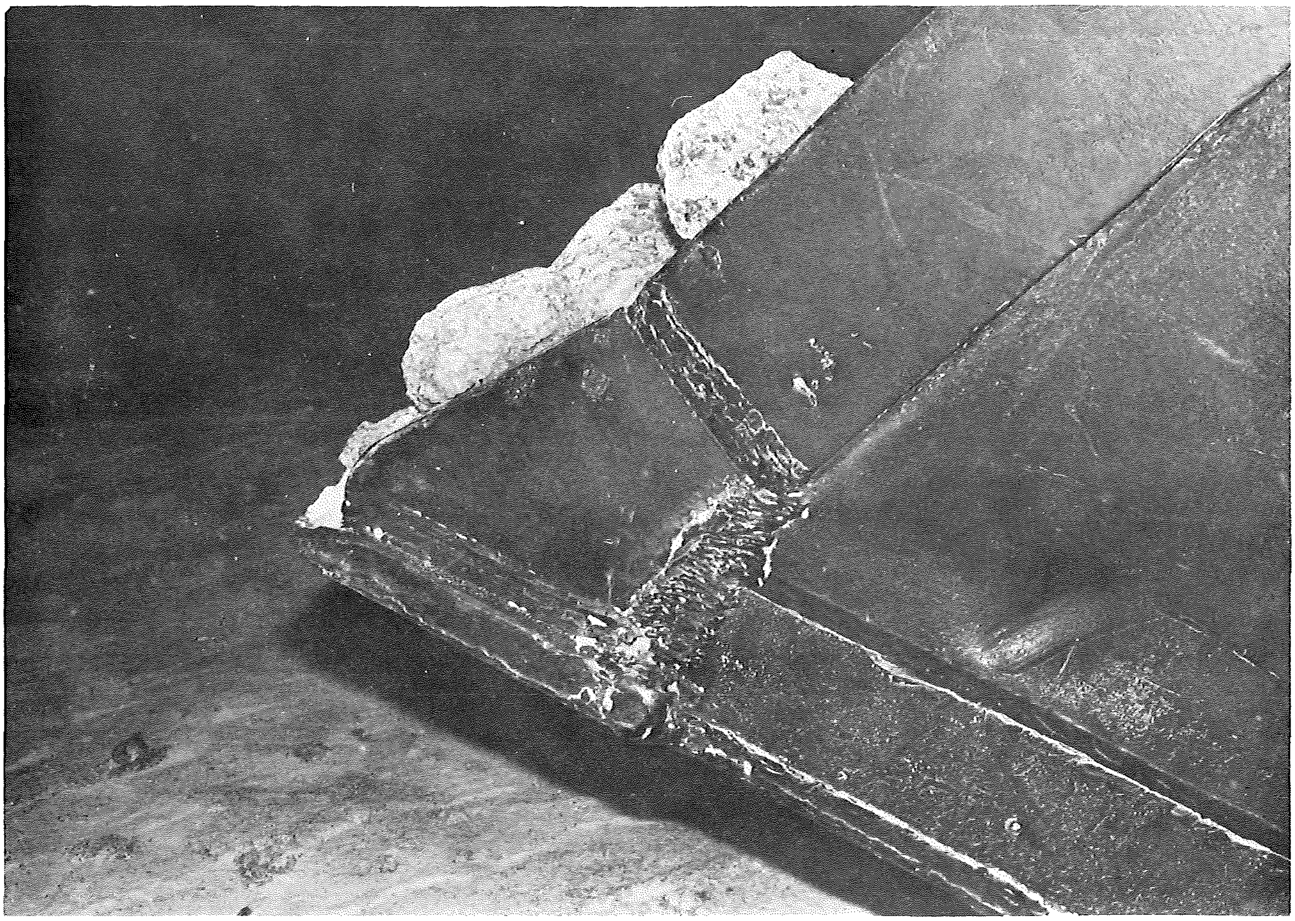


Figure 18. Shielded metal arc (covered electrode)multi-weld pass repair was necessary to repair the lip of this mining shovel.

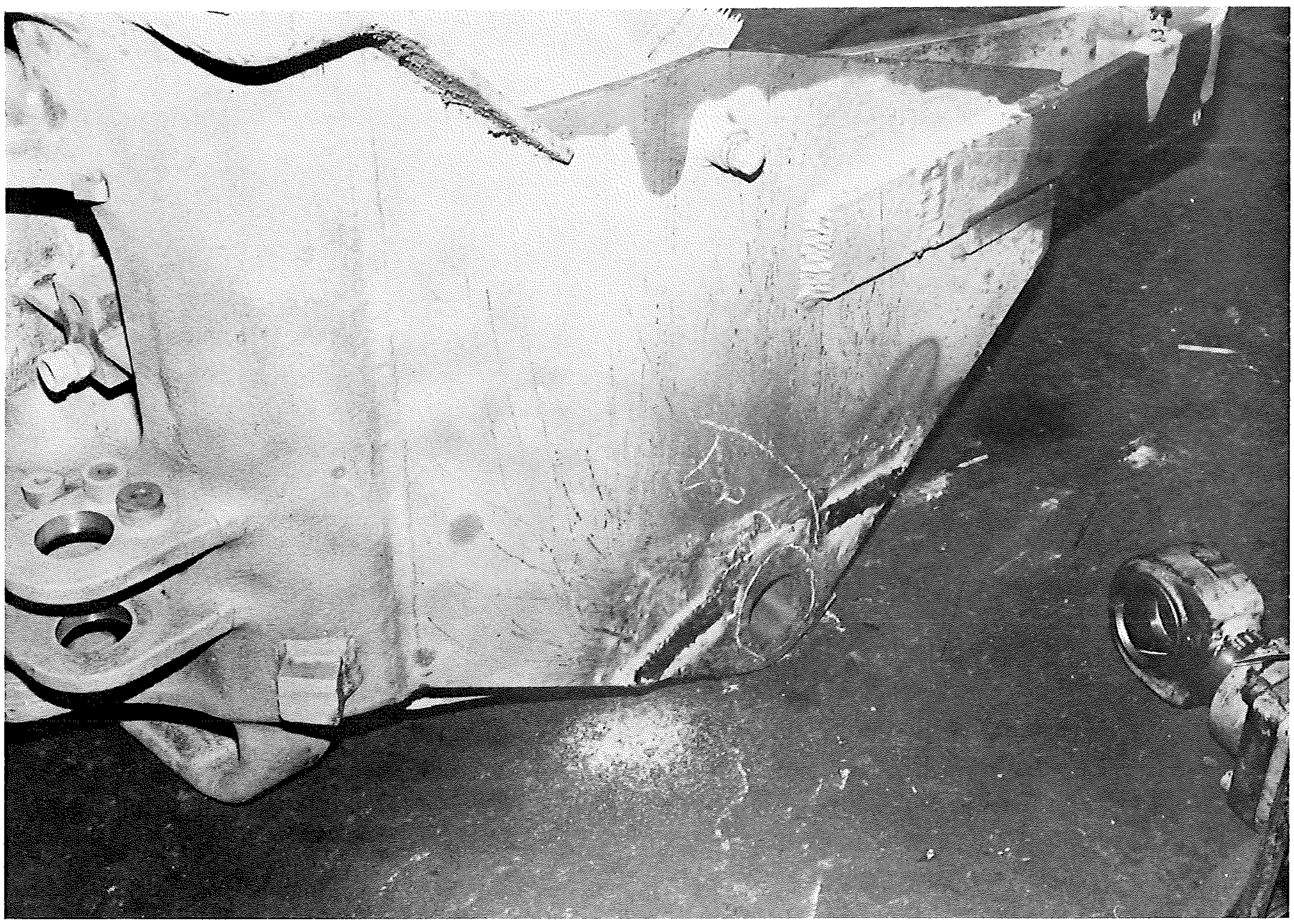


Figure 19. Weld repair of buckets is very common practice. Most mine maintenance shops keep in inventory the necessary bucket parts as shown in Figure 20 for quick weld repair.

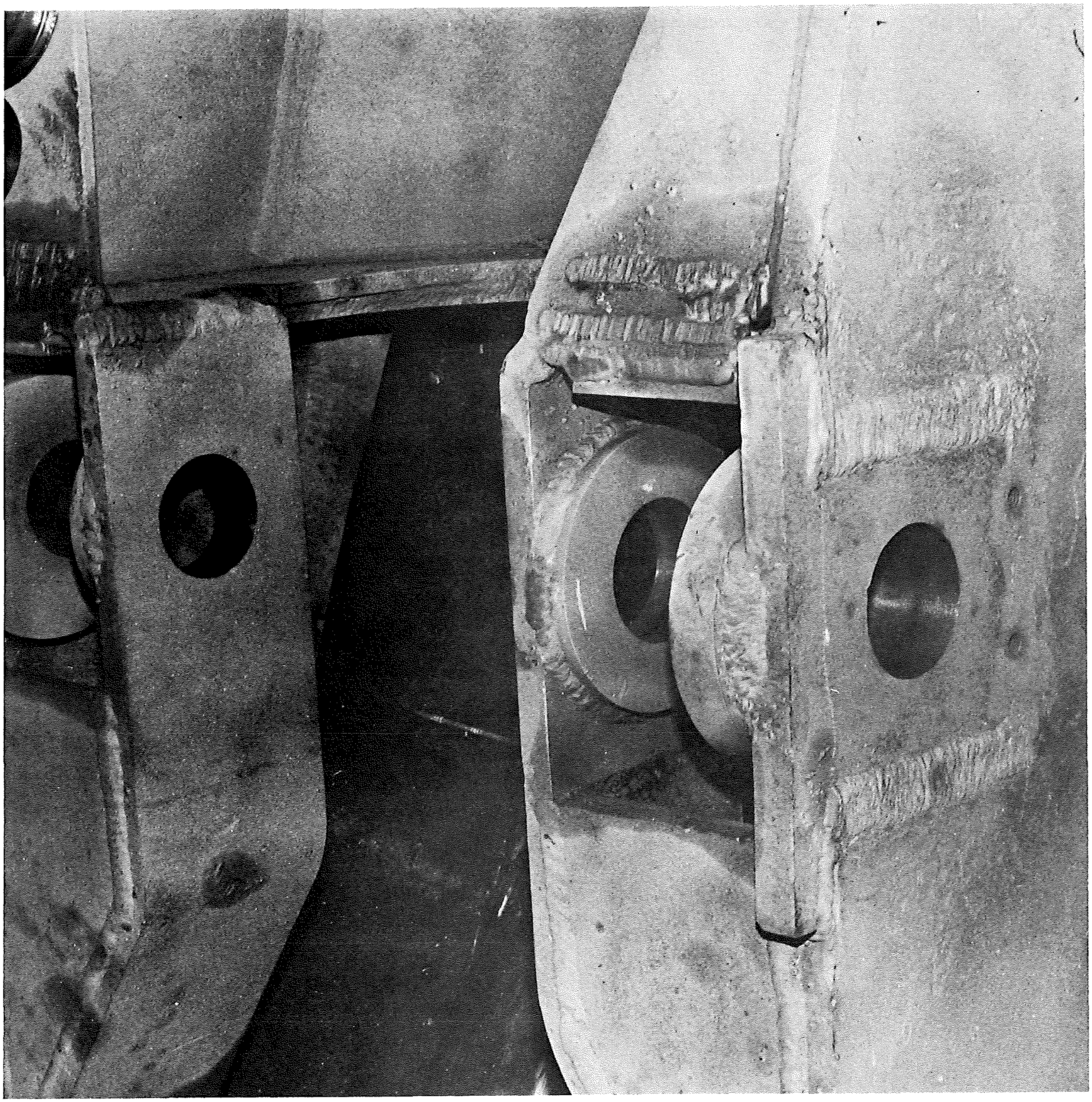


Figure 20. Weld repair of a bushing on a mining bucket. Excellent alignment and fitting are required.

Figure 21. The installation of a large bow section of a piece of mining equipment by welding to reduce stresses that have been causing failure and down time.

out of a large piece of equipment and a new bowed section is welded in to reduce stress that has been causing fracture in this piece of equipment. This example shows that competent engineering is required to keep a mining operation going.

The weld repair of mining tools, such as the repair of auger drill shown in Figure 22, requires welding high alloy and high carbon steels.

E. Buildup

Abrasion and fracture of essential components of mining machinery requires material buildup through weld surfacing processes. Weld surfacing is depositing filler metal on the surface of a base metal to either build up to the dimensions required or to produce special surface properties such as abrasion, impact or corrosion resistance. Maintenance shops are often reclaiming worn parts and there are definite economic advantages to having this weld capability. With ever-increasing costs of alloy steel components, the philosophy of throwing away used parts is quickly being converted to a save and reclaim policy. Mine management must become more aware of the great savings that are possible in capital expenditures by promoting and equipping their mine maintenance shops with the proper welding equipment, fixturing and engineering and welding talent to resurface and repair worn components of mining equipment.

Figure 23 shows serious wear on cable spool which will require buildup. Figures 24 and 11 illustrate a typical submerged arc process being used for building up a shaft and railroad wheels.

Covered electrodes are often used to build up parts or sections which are not easily accessible to automatic or semi-automatic equipment. Special high deposition (iron powder) electrodes are available to accelerate surfacing operations. Figures 25 and 26 show a large multi-pass buildup on the lip of shovels deposited with high deposition covered electrodes. Welding metallurgy

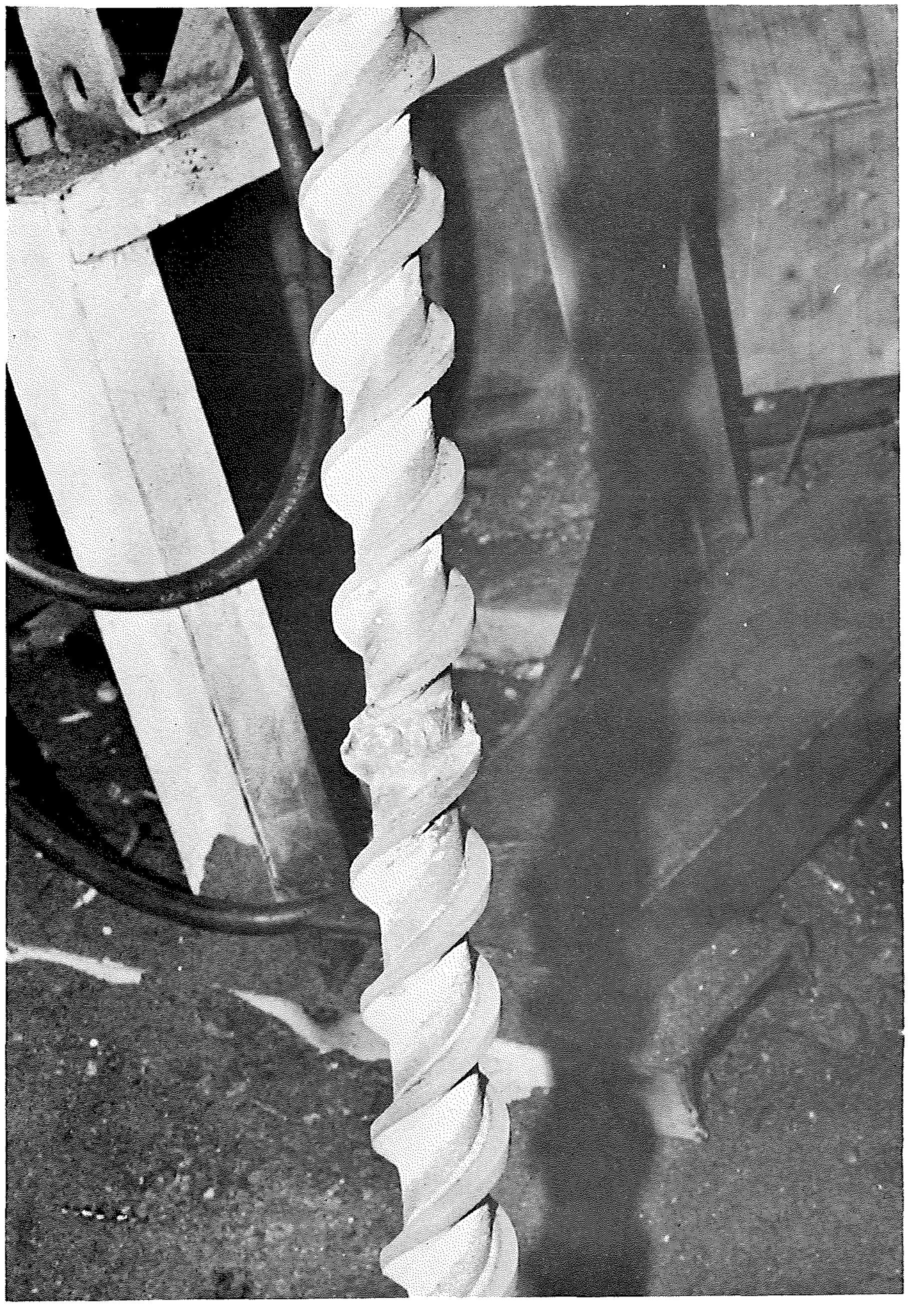


Figure 22. Weld repair of an auger mining drill requires special procedures to weld the high alloy and carbon steel.

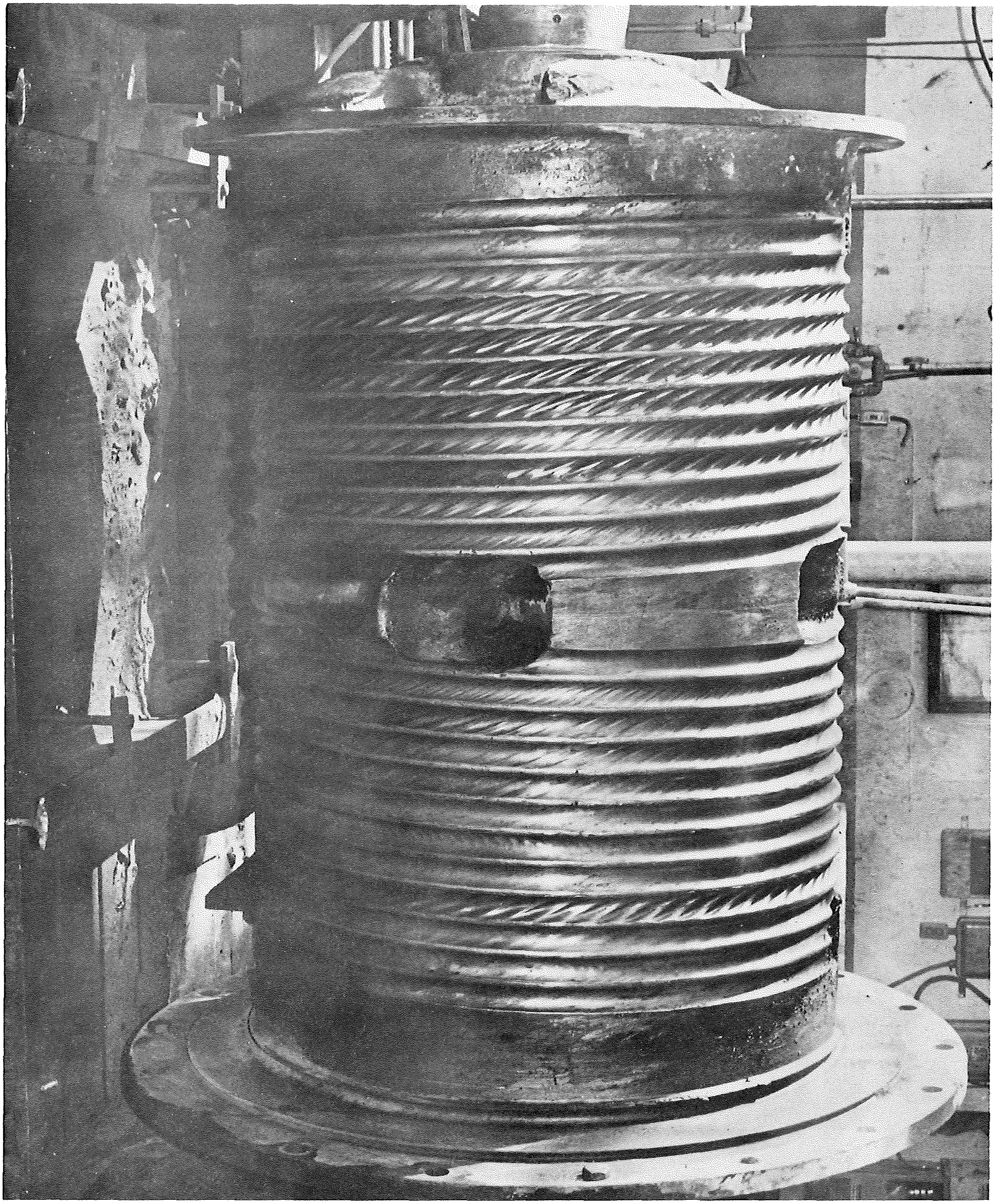


Figure 23. Cable wear on large spool can be repaired by weld surfacing following by a machining operation. There is a great cost saving in reclaiming large worn components of mining machinery.

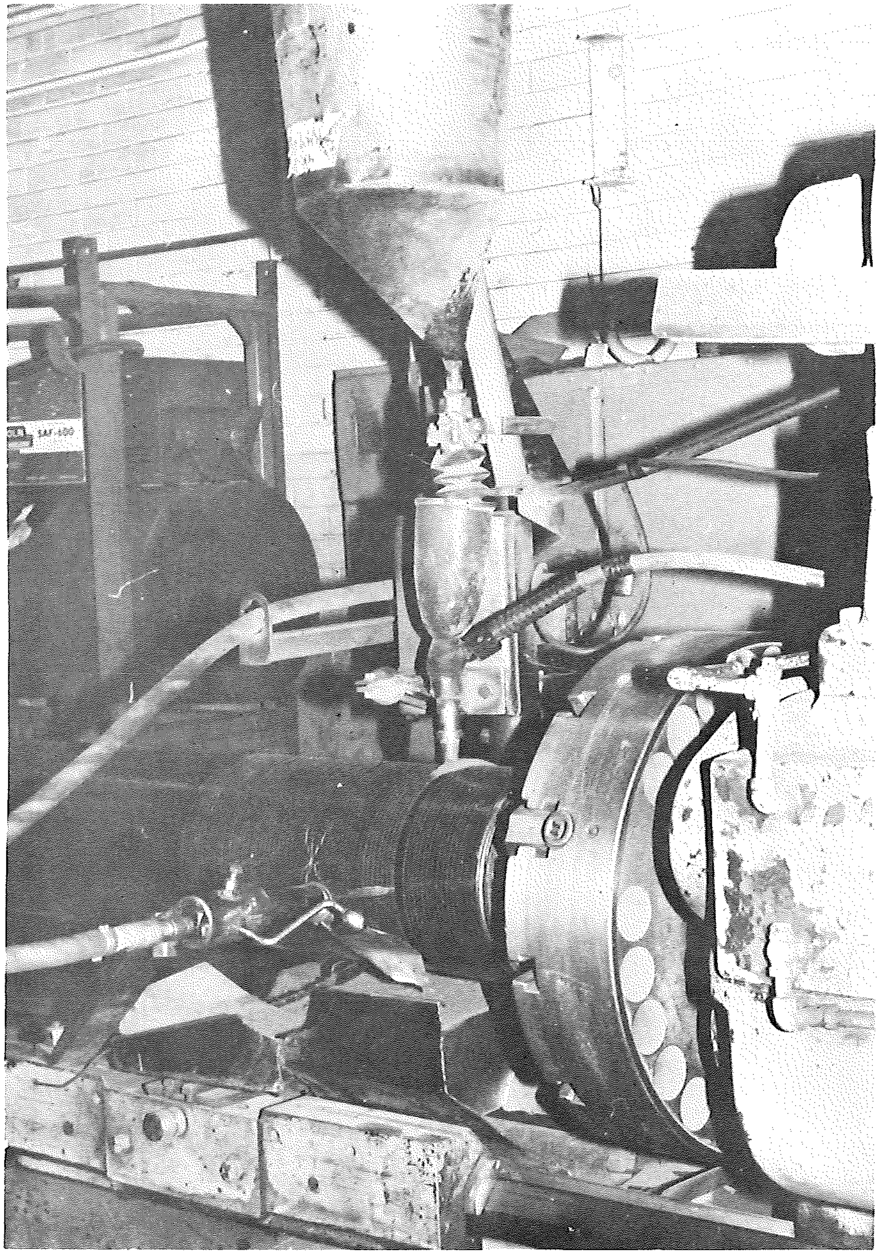


Figure 24. Weld repairing worn shaft by submerged arc welding surfacing process. Notice the fixturing that is required to properly use an automatic welding process.

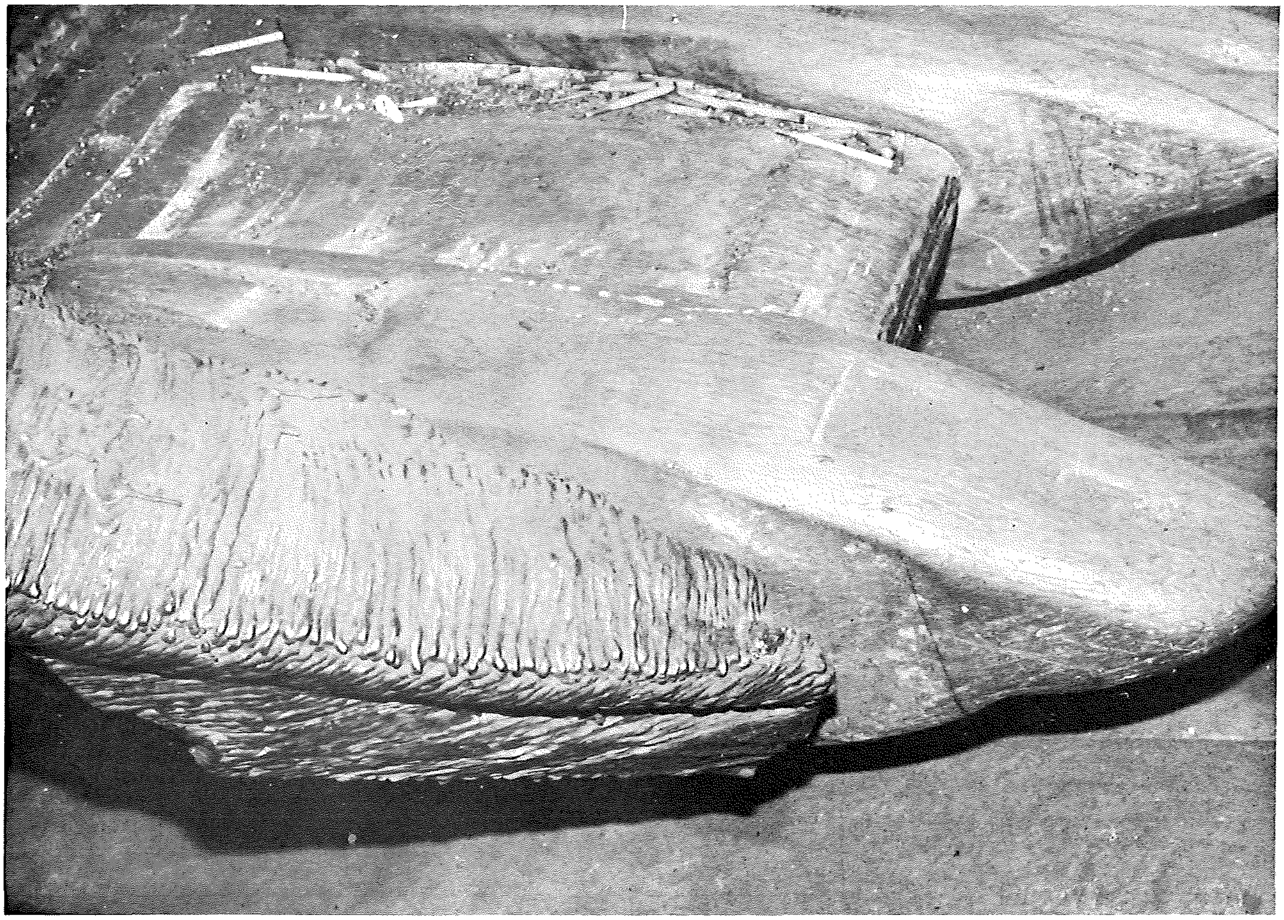


Figure 25. Large weld build up on shovel lip to reinforce lip and provide impact and abrasion resistance.

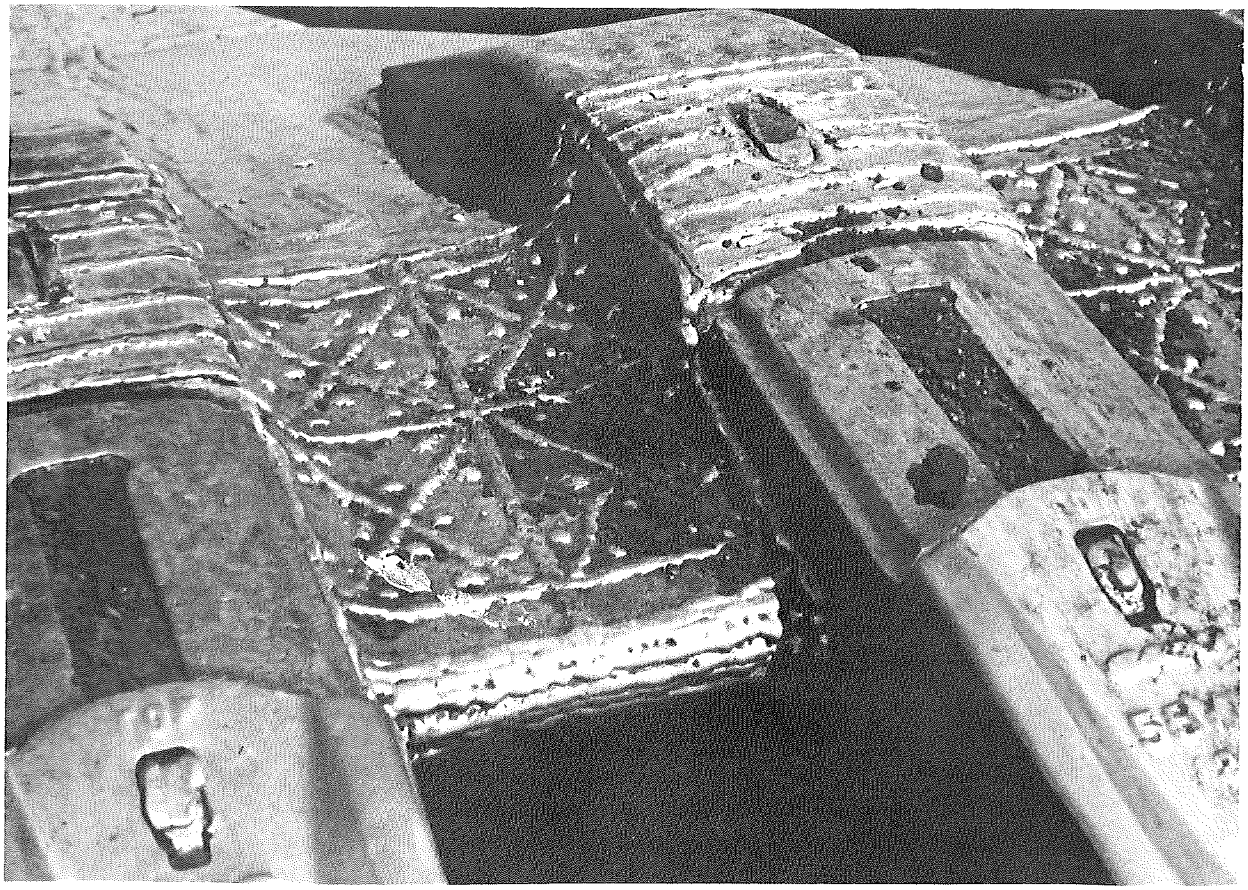


Figure 26. The hardfacing build-up pattern on the lip of a shovel which is used to resist both impact and abrasion.

concepts, such as properly using the Schaeffler diagram, can assist in guaranteeing the deposition has the desired properties.

F. Hardfacing

Hardfacing, which is a special surfacing procedure, involves depositing abrasion and impact resistant alloys on wear surfaces of mining equipment. Hardfacing involves 6% of all the welding done by a mining operation. It is evident that proper selection of hardfacing alloys must be based on metallurgical concepts and identification of the type of abrasion, where abrasion can be classified as low-stress scratching abrasion or erosion, high-stress grinding abrasion, and gouging abrasion. Properly used hardfacing concepts definitely increase the service life of mining equipment and with the use of a maintenance schedule for each piece of equipment, hardfacing can be utilized with uninterrupted mine productivity.

Figures 26 and 27 illustrate hardfacing deposition patterns used on surfaces of shovels. Only on direct impact surfaces is the deposition pattern a build up pattern. Where the abrasion is the only factor, then a specific hardfacing pattern is used to reduce the amount of metal deposited and the labor and material cost. The selection of hardfacing patterns varies from mine to mine since the abrasion is a function of the nature of the muck. Each maintenance department has its preferred pattern. If the muck is very fine, it will be packed in between the hardfacing pattern assisting in the abrasion resistance since muck will then wear on the packed-in muck.

Another concept of abrasion resistance can be seen in Figures 28 and 29 where wear resistant steel is welded onto the wear surfaces of the shovel. Figure 29 illustrates a very effective application of high manganese steel casted wear plates in large shovels. These cast wear plates are plug welded onto the shovel and offer very easy replacement by the mine maintenance department, since the plug holes are part of the casting and the casting is of a size which can be

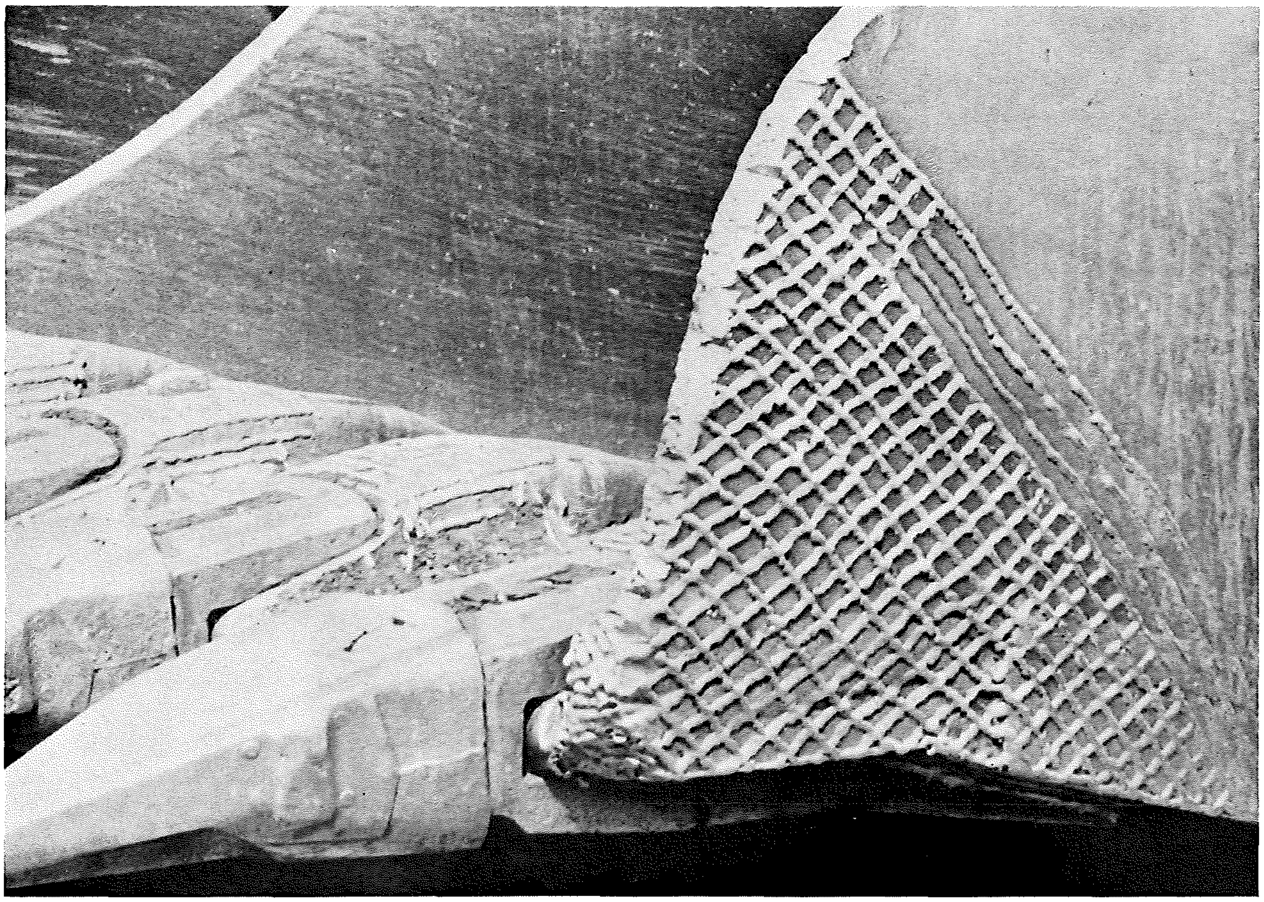


Figure 27. Hardfacing pattern on the side of shovel to give abrasion resistance.

Figure 28. Steel strips are welded onto the surface of the shovel and a hardfacing deposition is placed on top of these steel strips to give abrasion and impact resistance design for a muck which consists of larger rocks.

Figure 29. High manganese steel casted wear plates are plug welded into the inside surface of a large shovel being used in open pit mining: an excellent concept for shovel maintainance.

easily handled in the mine. Special dissimilar welding procedures were developed to weld these high manganese steel plates to the high strength steel of the shovel. The installation of these heavy wear plates requires the new shovel to be first worn by approximately 50% so that with the wear plates there is not an appreciable increase in weight of the shovel and thus loss in shovel efficiency.

G. Welding of Abrasion Resistant Steels

The welding of quench and tempered and abrasion resistant steel represents the special concern to the mine maintenance department. Quench and temper steels are being used for many applications where high strength and abrasion resistance are essential but also with an acceptable degree of toughness. These applications include armor plate for military applications as well as for the abrasion resistant needs of the mining industry. The following high strength alloy structural steels are some examples of commercial available steels for mining applications.

US Steel	AR type steel
US Steel	T1 type steel
J & L	Jalloy steel
National Steel	X-A-R steel
Armco	SSS-100 type steel
Vulcan	Astroalloy

The abrasion resistant steel usually contains approximately 0.30% C with sufficient alloying elements to allow the steel section to be quenched thoroughly to martensite. Even though many alloying elements, chromium, nickel, molybdenum, etc., have been used to promote hardenability, manganese has been the traditional alloying element for abrasion resistant steel. Manganese is an excellent and inexpensive hardenability addition and usually found when it is the primary alloy element as 1.5 to 1.9% of the steel content. Also, quenched and tempered manganese-base armor plate served our nation's needs well during World War II. However, since World War II more sophisticated and expensive low alloy steels have been produced with a wider variation in alloy content and heat treatment procedures. A typical heat treatment procedure for quench and temper steel involves a water quench and approximately a $1000^{\circ}F$ tempering to the desired hardness.

The carbon content of abrasion resistant steels has a major influence on the martensitic formation and must be optimized to achieve the necessary hardness and also to maintain sufficient toughness to reduce cracking susceptibility. Carbon will raise the temperature range of brittle fracture almost three centigrade degrees for each 0.01% increment of carbon present in the steel. For manganese steels, the carbon content must be maintained around 0.30% to achieve the necessary strength. But with the other alloying addition and increase in cost, it is possible to achieve the high strength with a much lower carbon content.

Initially most of the armor and abrasion resistant steels were welded using austenitic stainless steel electrodes with the shielded metal arc welding process. A typical austenitic electrode used during World War II would be 25-20 which contains 25% chromium and 20% nickel. The main advantage of these electrodes is that they produce austenitic fusion zones which do not transform into brittle martensite and are able to maintain a fairly high hydrogen content, thus reducing underbead cracking. The main disadvantage is the expense of using the high chromium and nickel content material.

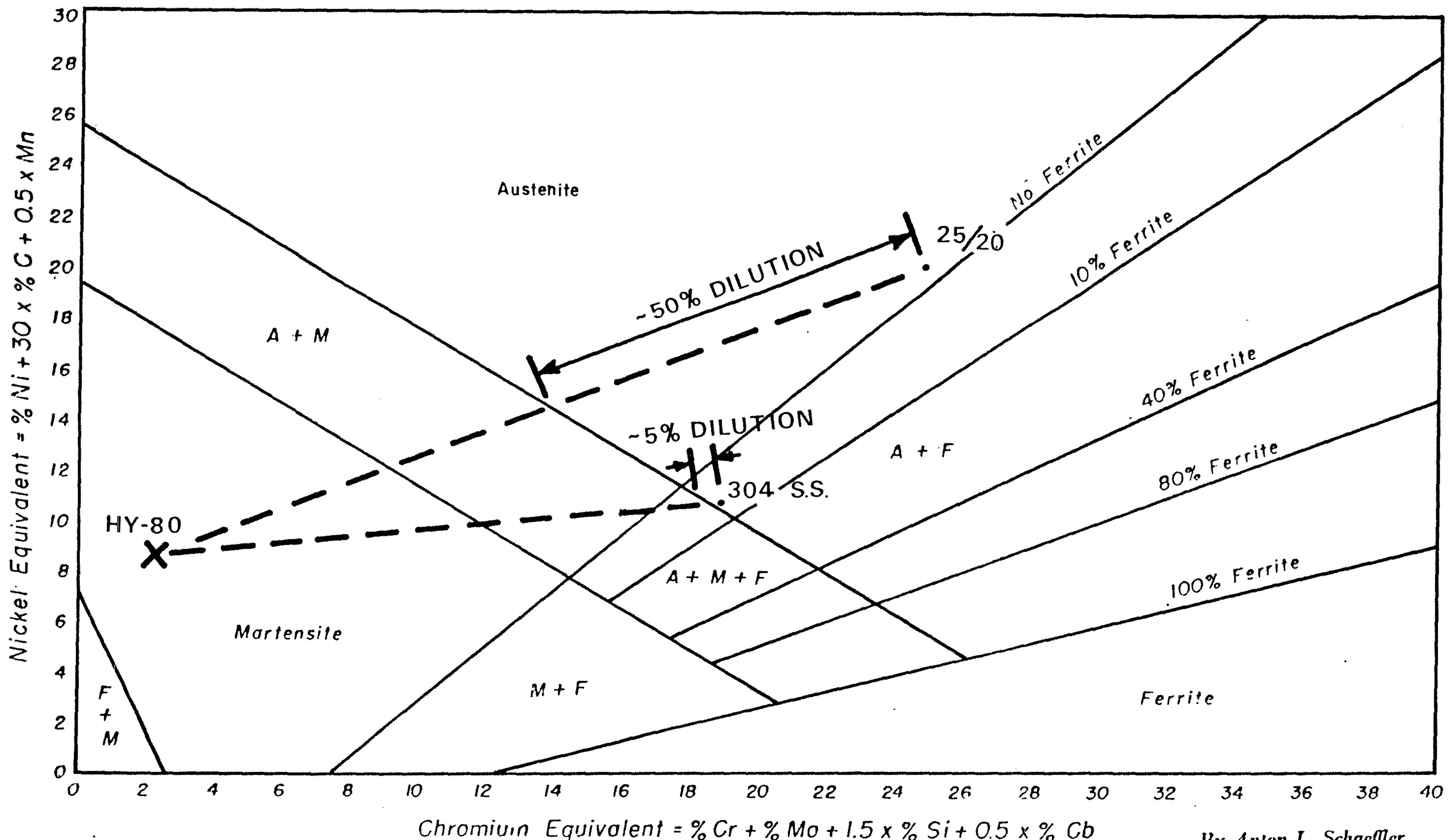
There is a fairly high consumption of austenitic electrodes for welding alloy steels in many mines. The use of austenitic electrodes was more prevalent in mining operations which did not have a scheduled maintenance program. With a scheduled maintenance program more planning as to use of materials (including filler) and personnel results. Where scheduled maintenance is an establishing engineering procedure, it was evident that the use of more economical welding materials, processes and procedures were practiced. Running machinery to failure promotes quick decisions and uneconomical maintenance practice. Austenitic electrodes are often used in the field or underground since they are less susceptible to hydrogen damage. Austenitic electrodes are often used without preheating. Hydrogen damage results from welding high strength steel in wet and dirty environments.

Maintenance engineers were found unaware of established welding metallurgy concepts. Their decisions were based mainly on their experience and the experience of the local welding suppliers. Commercial abrasion resistant alloys, with their large variation in composition, do require different welding procedures (preheat, filler, etc). Without the use of established welding metallurgy concepts such as the Schaeffler diagram, most maintenance engineers are very hesitant to switch to newer, untried alloys.

The Schaeffler diagram (Figure 30) and the recent Delong and Hull diagrams are effective nickel and effective chromium diagrams which allow prediction of the amount of each steel microstructural component developed in the fusion zone for a given dilution or penetration. The chemical alloying components of the abrasion resistant steel and filler wire are broken down into austenitic stabilizer (effective nickel) and ferrite stabilizers (effective chromium). This allows the welding of very complex alloys to be presented in a simple two dimension plot. Understanding the proper use of austenitic electrodes can be obtained from the Schaeffler diagram.

Figure 30 illustrates the use of the Schaeffler diagram for the selection of possible austenitic electrodes for a HY80 steel. Two possible austenitic electrodes are indicated with their effective chromium and nickel contents in Figure 30 . Lines are drawn in Figure 30 between each electrode composition

Constitution Diagram for Stainless Steel Weld Metal



By Anton L. Schaeffler

Figure 30. Use of Schaeffler Diagram for filler metal selection.

materials requires a good understanding of the role of hydrogen so that proper edge preparation, preheat and postheat treatment procedures can be established. The use of ferritic filler materials is definitely a more economical method of welding abrasion resistant steel and is mainly found in maintenance shops of the larger mining operations. A typical ferritic electrode composition commonly used is 7018. Another advantage of ferritic materials is the availability of ferritic welding wires and flux cored wire to be conveniently used with semi-automatic gas metal arc welding processes.

The most difficult welding being performed on these alloy steels are the dissimilar weld joints between the quench and temper steels and other structural steels. Such dissimilar joints are essential for the proper application of these steels in mining structure and equipment. The use of austenitic welding electrodes is one of the main approaches for these dissimilar weld joints. With proper preheat and procedures, low alloy welding rod can be successfully used for this application at a much reduced cost.

Cracking Problems in Welding Abrasion Resistant Steel

Cracking in the heat affected zone of the weld when martensitic structures are formed has been related to the presence of hydrogen. The source of the excessive hydrogen can be wet electrodes, or oily, wet or rusty surfaces. These conditions are typical to mining operations. The purchase and use of low hydrogen electrodes appeared to be well practiced by the mine maintenance engineers. Most mine maintenance welders were careful in protecting these electrodes before use and usually had baking facilities available to them. Some open pit and underground maintenance engineers purchased their low hydrogen electrodes in many sealed cans in which each can has only enough electrodes for a small job. Thus, opening these sealed cans in the mine environment just prior to welding minimized the contamination.

The cracking in the high strength alloy steels is found to have a delayed initiation. Hydrogen cracking occurs between -50^{o} to 150^{o} C and the period between each crack propagation increases with decreasing temperature. This hydrogen promoted cracking can be eliminated with preheating and post-heat treatment. The heat treatment of the weld region promotes a reduction in the cooling rate which allows for a less severe martensitic transformation and also gives more time for hydrogen removal. Figure 31 shows a preheating being performed in a mine maintenance shop.

The degree of preheat and post-heat treatments required depends on the thickness, chemistry of the abrasion resistant alloy, and the atmosphere temperature in which welding is occurring. Pre-heating operations, when used, were seldom based on specific procedures but were usually left up to the welders. Few maintenance engineers were found using the following "rule of thumb".

(a) if the carbon equivalent, CE, is less than 0.40 no preheat treatment is required,

(b) if the carbon equivalent is greater than 0.40 and less than 0.65 a preheat is suggested.

(c) if the carbon equivalent is greater than 0.65 both a preheat and post-heat treatment is suggested,

where the carbon equivalent is calculated by the equation

$$CE = \% C + \% Mn/6 + \% Cr/5 + \%Mo/4 + \% V/5 + \% P/3 + Ni/15.$$

Most mine maintenance engineers have not obtained or used the chemistry of their alloy steel for selection of welding procedure. Also the thicker the steel plate the greater will be the cooling rate from the weld region and the greater the probability of martensitic transformation. The necessary preheat temperature increases with the thickness of the plate section.

The observed cracks associated with high strength abrasion resistant steel weldments may be classified as one of four types. These main types of cracks

Figure 31. Preheating is an essential step to welding many of the alloys used in the mining industry.

are illustrated in Figure 32. Two of these types of cracks, underbead and transverse crack in the heat affected zone, have been found to be very sensitive to the presence of hydrogen. The notch or toe crack was found to be more susceptible to residual stresses but also was found to be influenced to some degree by excessive hydrogen pick up. The transition crack is found in the fusion zone and is more common to austenitic fusion zones and is associated with a large thermal expansion difference between the austenitic weldment and the high strength abrasion resistant steel.

Another type of cracking which is evident in thick high strength quench and temper alloy steel plate used in mining operations is lamellar tearing. Lamellar tearing is the result of long inclusion stringers resulting from inadequate steel processing at the steel mill. These stringers are orientated along the direction of hot rolling and represent a discontinuity in the plate which can promote cracking if stresses accompanying welding act in a direction perpendicular to the plate. Lamellar tearing can be avoided by proper inclusion control at the steel mill. But more important to the mine maintenance engineer, this cracking can be eliminated by proper joint preparation and design. Figure 33 illustrates how some joint designs are subject to residual stresses perpendicular to the steel plate. Notice with changes in design such stress situations can be reduced. Usually this type of cracking is found in steels an inch or more in thickness and with tee-butt welds or corner welds.

Cracking from lamellar tearing has been found to occur in both the heat affected zone and the parent metal unaffected by the heat but within the stress concentration area of the weldment. The cracks have a step-like path appearance with a portion of the crack propagation parallel to the plane of the plate and accompanied by shear fracture in the direction roughly perpendicular to the plane of the plate. The positions of crack propagation parallel to the plane

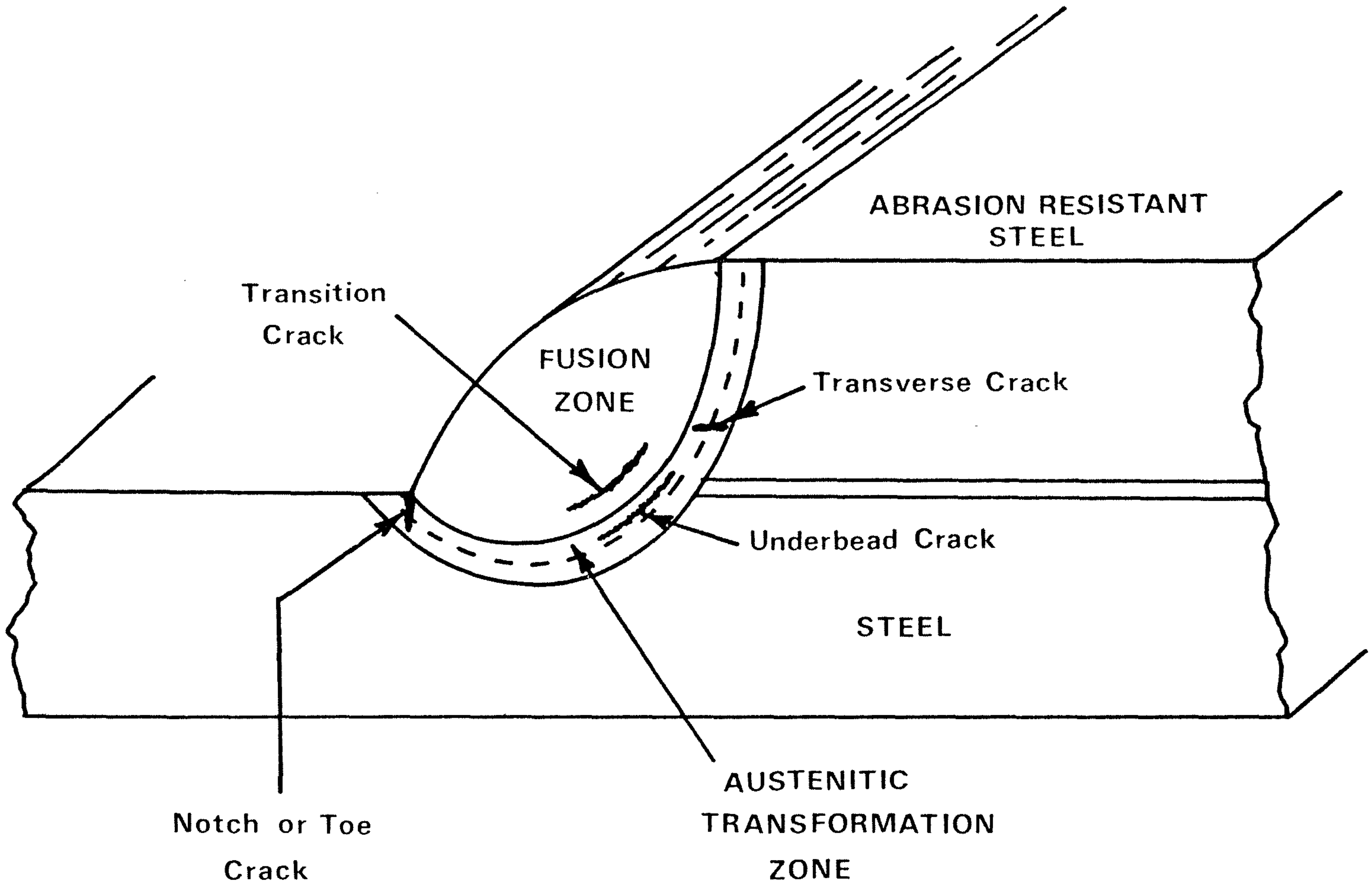


Figure 32. Types of cracking associated with abrasion resistant steel weldments.

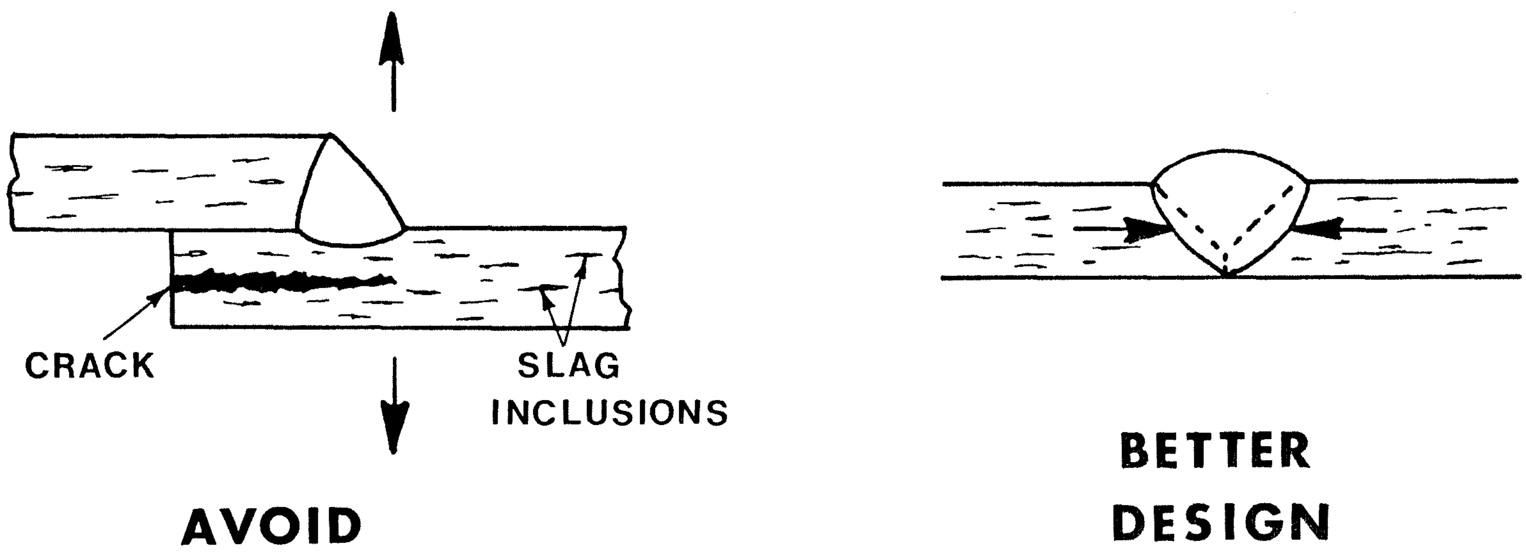


Figure 33. Design change to eliminate lamellar tearing.

of the plate are usually associated with planar silicate or sulfide inclusions.

VI. Weldability and Welding Procedure Information

A serious problem which we became aware of during our visitations is the nature of source of technical welding information with which mine maintenance engineers are working. The metallurgical and weldability information necessary for use of these alloy steels in the mining industry comes mainly from verbal communication with local suppliers. That is, the ability of a mine to join new available alloys is most likely dependent on the previous experience of the local electrode, wire and welding equipment salesman. The use of a new alloy steel is considered with much caution because the maintenance engineer realizes that it will take time to develop proper procedures. Large mining operations have taken time to develop welding procedures and select material based on optimum service and economy. However, many of the smaller mining firms do not have the time and exploratory capital to invest in the longer term gains of proper material selection investigation and are solely dependent on information from the suppliers.

The welding literature, which must serve an ever increasing and diverse welding industry, is also becoming a less likely information source for mine maintenance engineers. In general, the American Welding Journal and related welding journals are not being read by the mining industry. A new mining industry maintenance quarterly would be an excellent method to revive technical communication in the mining industry. We have found a number of very experienced maintenance engineers at each mine, and with editorial assistance these engineers could make important contributions which would assist in improving the optimum service life of equipment and structures and thus improve the efficiency of the mining operations.

VII. Welding Training and Education

Welder Training

Availability of qualified welders for the mining industry has become a concern in certain regions of the nation, especially in the western states (Montana, Wyoming, Colorado, New Mexico, etc.) which are experiencing the tremendous growth in mining operations with new efforts in coal, oil shale and uranium mining but also have a limited labor market. Established mines in the more populated states draw upon a more stable labor market and usually seek welders who have been trained in established welding schools.

Many of the larger mining operations, especially western operations, have instituted their own welding training program to guarantee the availability of qualified welders for their specific welding concerns. In many mines there is an effort to train general maintenance personnel rather than a position classified as just welder. In small operations the training and utilization of more general maintenance personnel is a serious economic concept. Some of these training programs have their own facilities on site to train and qualify welders. Usually, these training programs are centered around a very qualified and experienced welder, and in fewer cases welding engineers. Being on site also offers the trainee welding experiences not evident in normal welding schools. Figure 34 shows a welding booth for training maintenance personnel at a mine. The organization of some of these welder training programs can also be seen in excellently prepared literature and exhibits used, such as illustrated in Appendix C and Figure 35. Such established training programs reflect an excellent understanding by the mine management of the importance of a competent mine maintenance department.

Engineering Education

From both our visitations and the questionaire, it was obvious that the

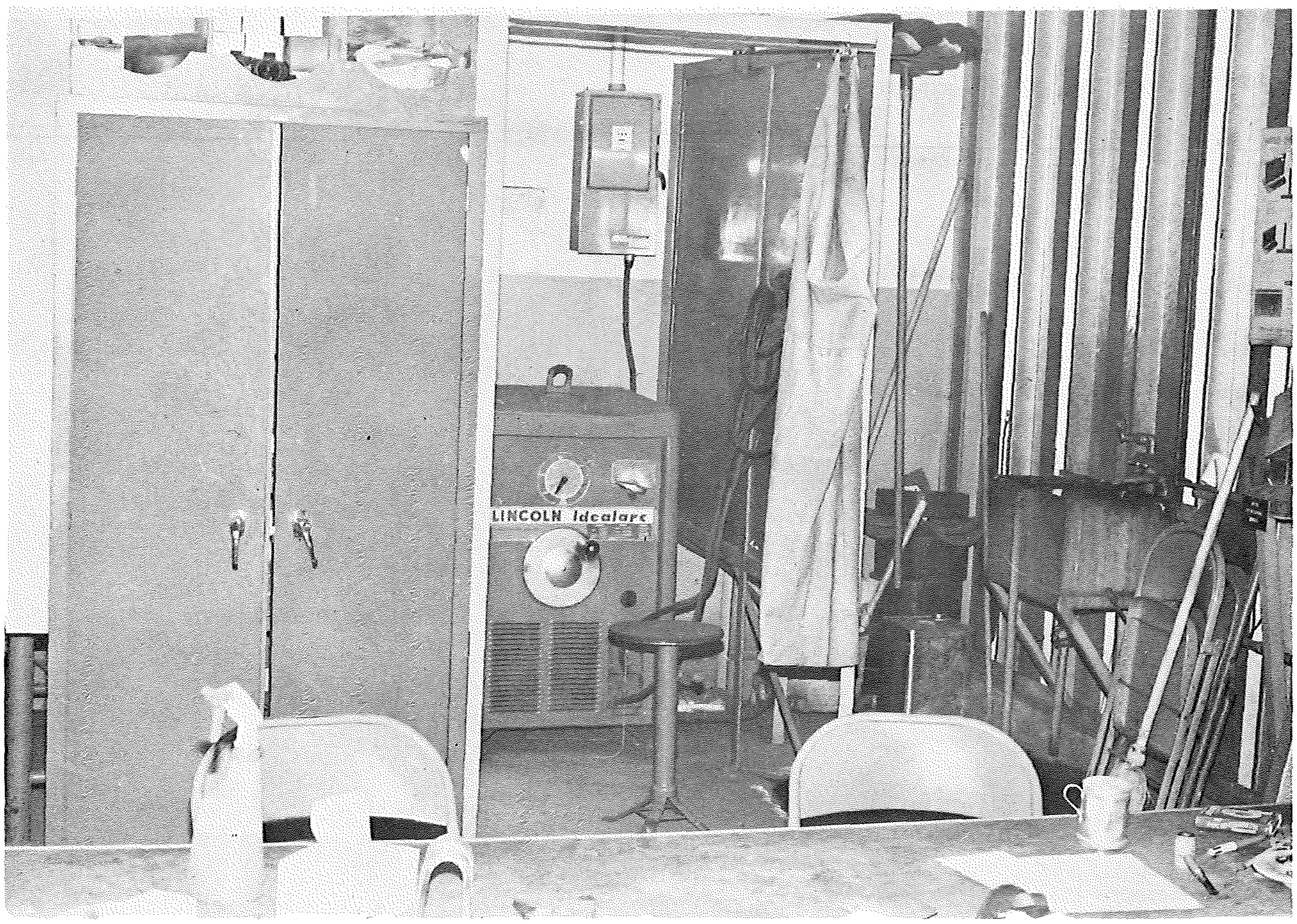


Figure 34. Welder training booth which is part of a welding school at a mining operation. Welding training programs have been found useful in guaranteeing competent maintenance personnel and maintaining excellent employee morale.

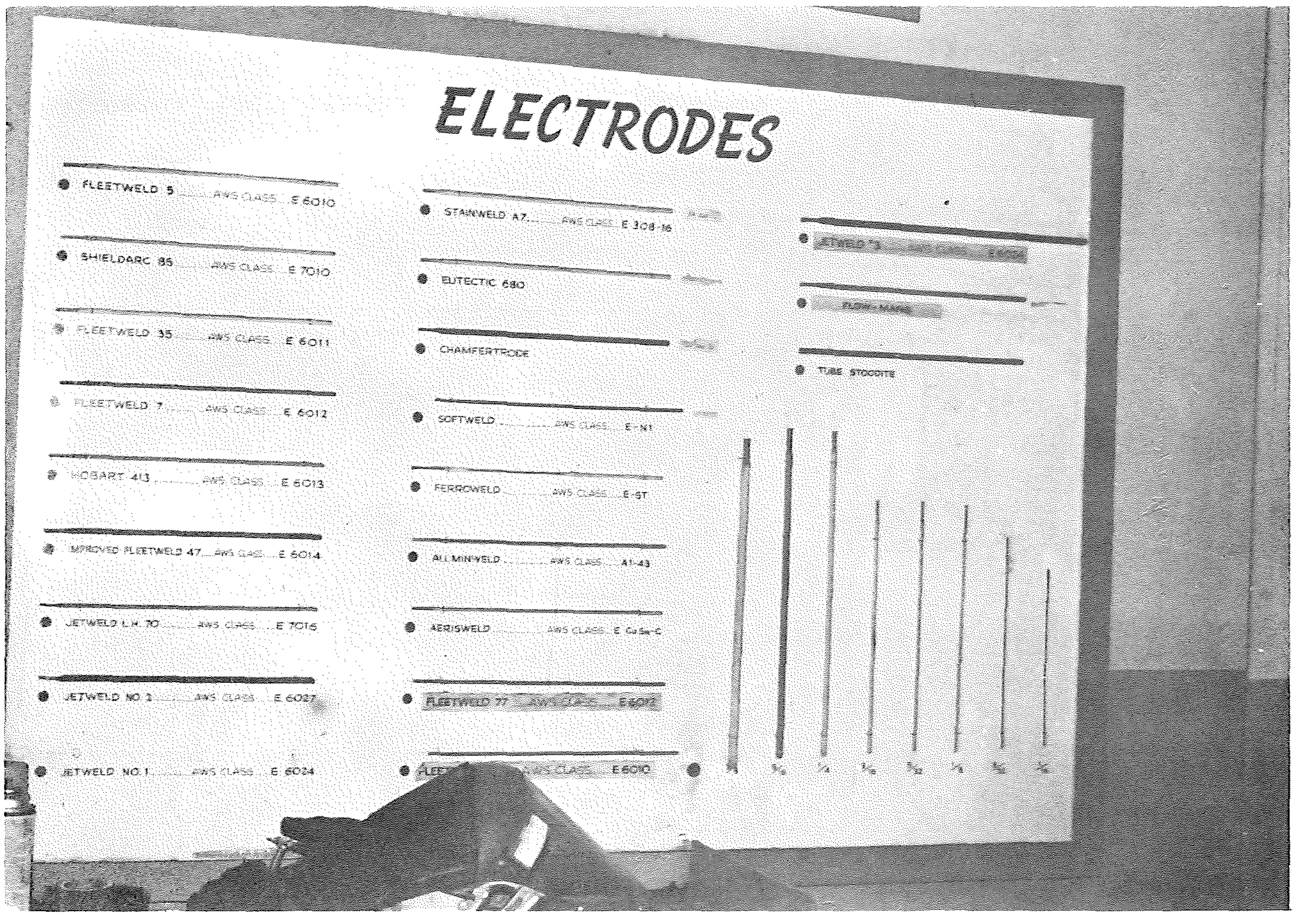


Figure 35. The electrode selection chart illustrates the degree of preparation going into some of the welder training programs at mines.

nation's engineering programs need to spend more time in design and fabrication concepts. The survey revealed that most mine maintenance engineers find that the needed fabrication principles found in new engineering graduates was somewhere between inadequate to non-existent. Some maintenance engineers were extremely disappointed in how poorly qualified today's engineering graduates are in reading and preparing engineering drawings. They suggest that the engineering school return to basic engineering education with emphasis in mechanics, drafting, design, fabrication concepts, material selection, hydraulics, and other very obvious engineering skills that are important to the mining industry.

VIII. Welder Health and Safety

Welding processes by their nature involve high energy input, fuel and protective gases, intense optical and ultraviolet radiation and a change in air quality. This requires well planned welding facilities and techniques not only to guarantee weld quality and integrity, but to also maintain a safe and healthyenvironment for the welder. To maintain safe and healthy welding practice for surface welding has required the purchase of new equipment and further education of welders. Underground welding offers a much more complex problem since welding environment usually consists of a moist, dark and space-limited situation which puts the underground welders into a more difficult safe working condition. Fume generation and removal is a major concern. Figure 7 illustrates the amount of fume generation experienced in a typical underground steel fabrication situation. Many of the underground welders wore air filtering units during welding.

It is very apparent that the mining companies are very concerned over mine welding safety and health for there was no apparent lack of availability of safety equipment. Fume ventilation systems were evident at most maintenance shops as shown in Figure 36. Welding safety posters are very commonly displayed in welding areas. It is apparent that underground welding requires a special training to educate the mine welders as to both safe welding procedures and concern for his own health. This is another reason for mining companies to have their own welder training program.

Even though there were safety and health programs, there was evidence in many mines of the typical problem of welders not using the available and required safety and health equipment and procedures. Welders were found welding without gloves as shown in Figure 37. Commonly, gas cylinders were found not effectively tightened down as shown in Figure 38. It is very apparent that the underground welder must be extra cautious with the limited lighting to make sure the layout of the material and process equipment is safe. Figure 39 illustrates a typical problem for an underground oxy-acetylene cutter in making sure he does not cut across his own fuel hoses. There appears to be a greater concern over safe and health practice in the younger welders, which is probably the result of modern awareness of the environment and personal health. If this observation is correct, it is hoped that the mining industry will see a decrease in injuries due to personal carelessness.

IX. Welding Economics in the Mining Industry

From the questionaire sent to the mining operators in the United States, the following statistics were obtained. It was determined that 5.8 employees out of 100 mine employees perform some welding and from the point of view of their mining operation, they are welders. From the questionaire it was determined that the following welding expenditures are made annually for each of these welders.

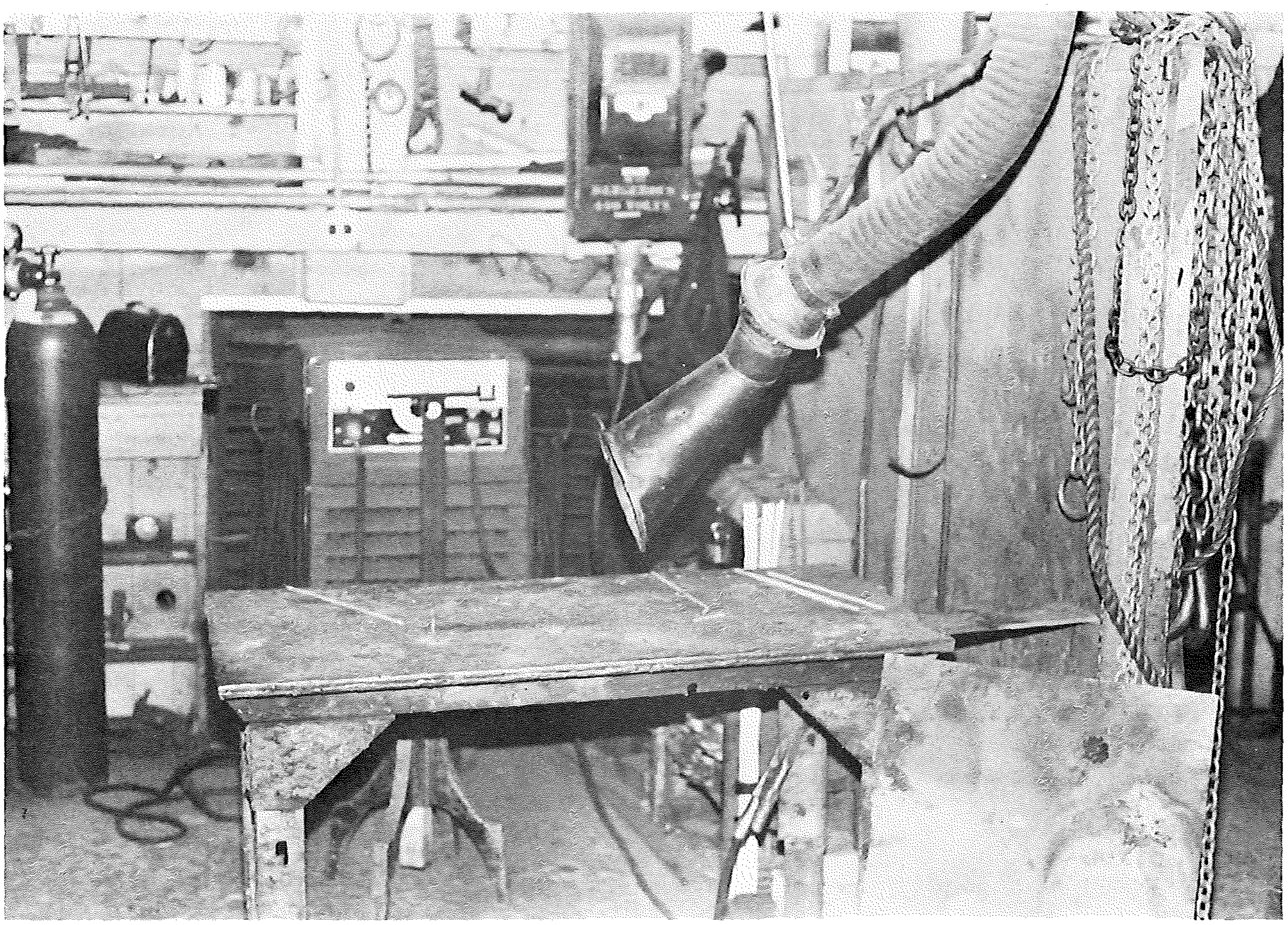


Figure 36. Welding fume removal equipment commonly found in mine maintenance shops.

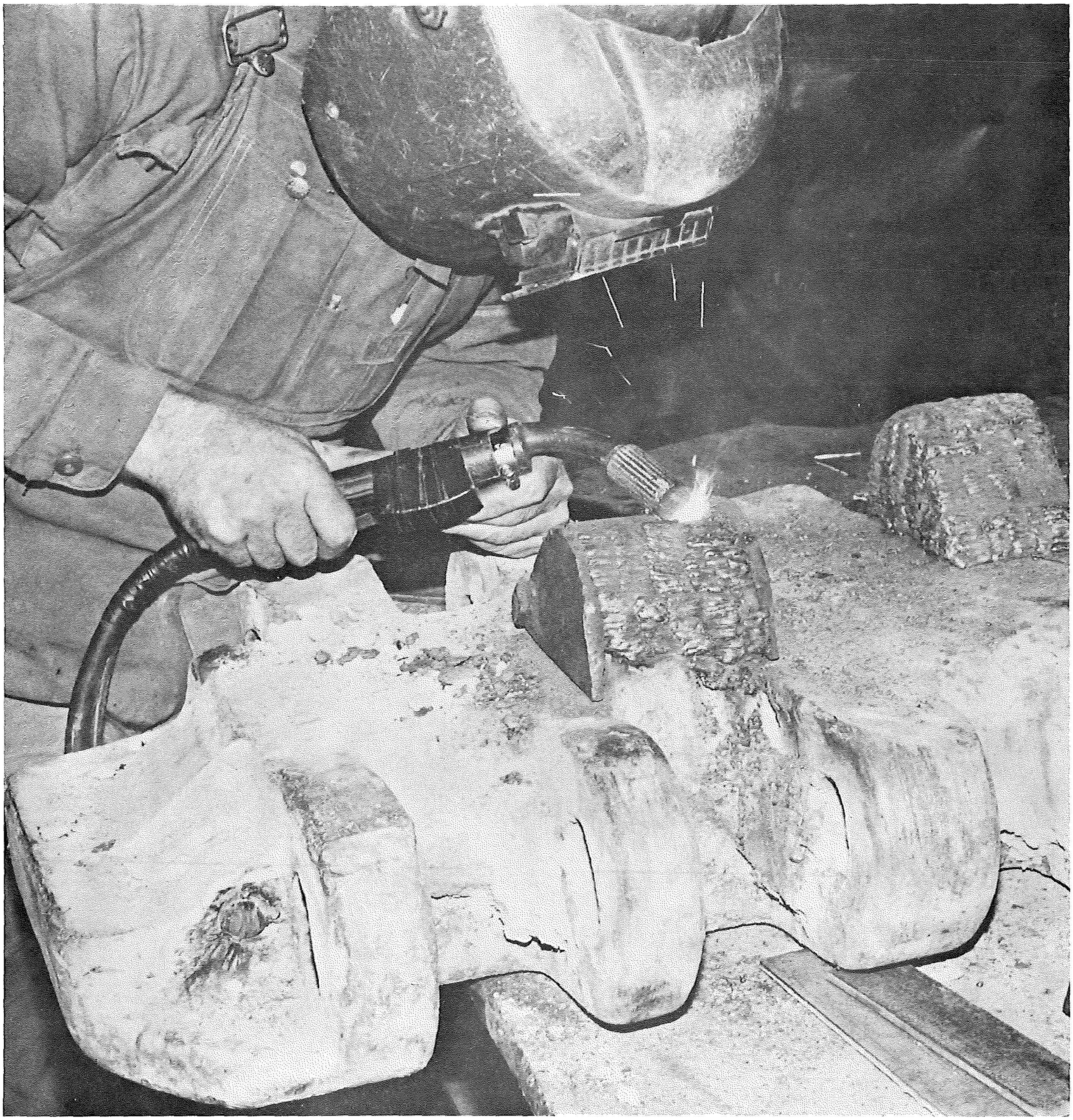


Figure 37. Welding without the protection of gloves is a common welder attitude problem.

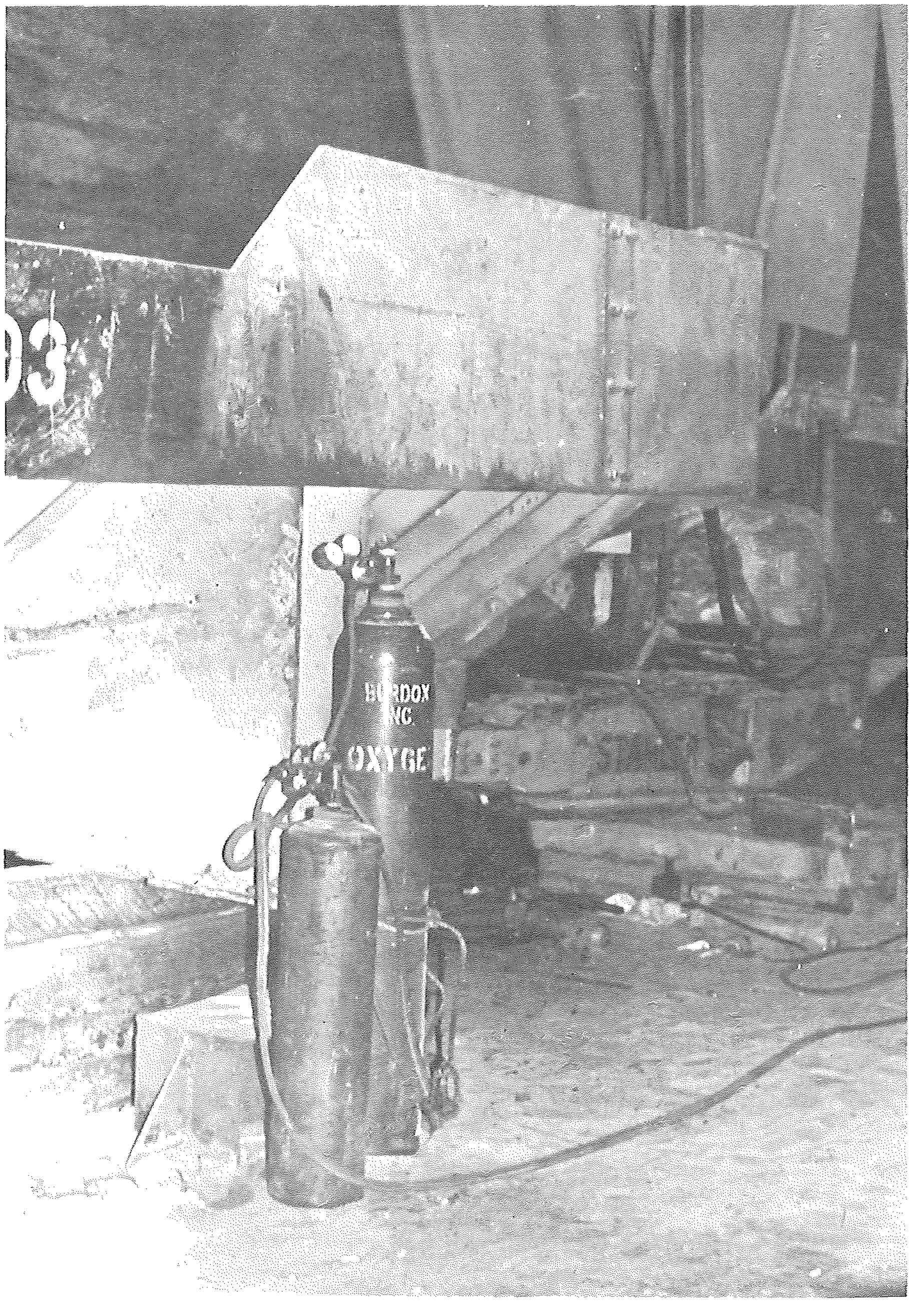


Figure 38. Gas cylinders in the mine are commonly found inadequately tightened down..

Figure 39. Oxy-acetylene cutting requires care in keeping fuel hoses from flame.

	Cost per welder	Mining Industry (Based on 500,000 mine employees)
electrodes	$1078	$31M
wire	218	6.3M
gas	468	13.5M
equipment	622	17.8M
Total	$2,386	$68.6M

Based on the number of 500,000 mine employees in the United States, the projected total annual expenditure by the mining industry for welding equipment and expendables is approximately $70 million dollars. This represents 5% of the total sales of the welding expendables and equipment in the United States.

X. Survey of Mine Welding Research Topics

A number of possible research topics were suggested to mine maintenance engineers in the welding questionaire. From the results of this survey the following topics were found valuable for support. These topics are listed in the order in which the maintenance engineers consider them important:

Welding manual for mine maintenance welding

Hard surfacing materials

Welding techniques for hardfacing

Proper alloy selection for maintenance welding

Proper preheating procedures

Welding high strength low alloy steels

Dissimilar metal joining

Proper fixturing in welding

Determining economical welding practice

Proper weld design for mining equipment

Proper use of austenitic electrodes

XI. Summary and Recommendations

It is most apparent from the information collected by the mine visitation interviews and the questionnaire that the welding operations conducted in most of the mining industry are viewed as incidental, though necessary, to the principal function of handling ores. The apparent objective is to cause components to stick together adequately for reasonable periods of time.

Although this viewpoint may be the traditional approach, it is questionable where it is based on sound economics and good engineering. The desireability of using the traditional approach depends on a number of factors including the severity of the application of the weldment, safety considerations and the cost of shut downs to re-repair or re-assemble a unit. With today's mine operations depending on much larger and fewer pieces of equipment, a much more serious concern over efficient maintenance engineering, and thus welding, must be addressed.

There are a number of welding concerns and applications which could be improved through research and better communication between the mine maintenance engineer and the welding suppliers. Some of these are listed below:

(1) General guidelines for mine welding operations.

Each operation has its own methods for selecting welding processes and materials and performing the welding function. Some are quite innovative. There is some cross-fertilization of ideas via salesman of welding supplies but this is usually very localized and haphazard.

Recommendation: A brief information sheet issued periodically with interesting and novel approaches to mine welding problems sent to all mining operations in the United States.

(2) Hard surfacing.

The responses by mine maintenance engineers indicated a prime need for more information on hard facing materials and methods.

<u>Recommendation</u>: Establishment of a research program to evaluate currently used hard facing operations and materials. It is essential in today's economics to determine optimum use of these expensive materials and processes. Also to establish longer term research into development to more economical concepts of hard facing.

(3) <u>Weld Preparation Techniques</u>

Generally, edge preparation and cleaning is reasonably well done in surface shops. In underground operations it is frequently ignored to the detriment of the weld quality.

<u>Recommendation</u>: A study to determine the most usable tool kit to be prepared for the underground welder to enable him to deal with the variety of problems such as inaccessability, moisture, dirt and lack of light.

(4) <u>Preheating and Post Heating Treatements</u>

There is a general disregard or lack of understanding for these operations, again to the detriment of the weld.

<u>Recommendation</u>: The development of a manual of innovative techniques and methods to determine sufficient temperatures to perform these operations in the field and in the mine.

(5) <u>Use of Austenitic Filler Materials</u>.

Austenitic electrodes which are expensive, were generally found to be used without much understanding of the metallurgy involved. These electrodes are very useful in welding high alloy steels and in particular for welding dissimilar metals. Proper understanding of these alloys is essential if the desired mechanical properties are to be achieved.

Recommendation: Development of the proper procedures for use of austenitic filler materials for many of the common applications found in the mining industry and dissemination of this information in readily understandable terms via carefully prepared data sheets.

(6) Welding of New Alloys

This is an area where most mine maintenance engineers feel the need for more pertinent information. Most mine maintenance engineers use alloys based on experience and are usually very hesitant to apply new, and sometime more economical materials.

Recommendation: The development of a manual summarizing the proper welding procedures and the best applications of new, as well as the present alloys applicable to the mining industry is needed.

(7) Welding Expenditures

The mining industry of the United States is spending an estimated 70 million dollars per year on welding expendables and machinery. This is approximately 5% of the total sales of the welding suppliers. With the present and future growth of the mining industry of the United States to produce a stable national mineral and energy supply, these welding expenditures are anticipated to experience a major increase. The effect of national energy projects, such as pipeline construction and the developing western coal and oil shale mining operations, on the availability of welding expendables must be seriously considered by the welding industry.

Recommendation: The Bureau of Mines sponsor a symposium for the welding industry to describe its present and future anticipated needs.

(8) Welding Journal Material

There appeared to be an almost total lack of interest among maintenance engineers and welders in reading technical literature on welding.

In some cases this was probably because they felt the material was too technical. In most cases it is probably because most of the material in the literature is focused on applications with which the mining people do not associate. Still there is much benefit to be derived by better review of the published literature.

Recommendation: Development of a periodical publication that would excerpt from the welding literature that information particularly pertinent to the mining industry. This periodical could possibly be published by the American Welding Society with a Mining Industry editor.

(9) Welding Engineering Education

Mining supervisors stated concern over the ability of today's new graduate engineers to handle welding and maintenance engineering problems. They suggest more problems in the engineering curriculum to introduce solution concepts to handle the every day problems found in maintaining machinery. More effort is needed in design and assembly concepts, engineering drawing, hydraulics, materials selection, and forming and joining processes.

Recommendation: Bureau of Mines sponsored symposium for the engineering educators to describe the technical needs of the present and future mineral industry. This symposium is to address itself to the preparation of tommorrow's mining engineers.

WORK SHEET

1. Name of Firm

2. Location

3. Type of Operation

4. Name and title of individual having specific responsibility for welding.

5. Extent of welding facility.
   a. Surface

   b. Subsurface

   c. Welding personnel
      (1) Number of people.
      (2) Qualifications.

6. Principal welding applications

a. Tools

(1) Materials

(a) Preheat - postheat

b. Structures

(1) Materials

(a) Preheat - postheat

c. Surfacing

(1) Materials

(a) Preheat - postheat

d. Repair

(1) Materials

(a) Preheat - postheat

e. Rail

(1) Materials

(a) Preheat - postheat

f. Other

7. Types of processes used
   a. Manual (covered electrode)
      (1) Electrode selection - cost, type, specs.

   b. Automatic
      (1) wire - cost, type, specs.

      (2) gas

   c. Semi-automatic (MIG)
      (1) wire - cost, type, specs.

      (2) gas

d. Oxyacetylene

(1) welding and cutting

e. Fixturing

f. Costs

g. Ideas for modifications

8. Principal welding problems.

   a. Accessibility

   b. Availability of equipment, supplies & technical information.

   c. Types of failures

   d. % of rework

   e. Testing procedures

      (1) Destructive

e. Testing procedures

(2) Nondestructive

f. Moisture problems.

g. Codes involved.

9. Cost data.

a. Equipment

b. Supplies

c. Personnel

10. Needs

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We recognize that in your mining operations the matter of welding, whether for structural applications, to reassemble equipment that has been segmented to permit haulage or for maintenance purposes, is an incidental activity. However, it is an item of considerable expense and of considerable importance to reliability of operation of a unit and to safety. Compounding the situation is the fact that many new alloys are being used in equipment to complicate the welding process.

The department of Metallurgical Engineering of the Colorado School of Mines is engaged in a study to determine the specific problems involved with welding operations in the mining industry and to aid in formulation of measures that will be of assistance to the mining industry. The program is supported by the U. S. Bureau of Mines.

Your input to this study is important to us. Time and money limitations do not permit visitation to all of the sites that would be desirable. Accordingly, we are asking you to help by having the attached questionnaire filled out and returned promptly.

David L. Olson
Project Director

William M. Mueller
Associate Project Director

WMM/evw
att:

Appendix B

		Number/ Percent
1.	Number of employees at your mine.	
2.	Number of welders.	5.8 welders/100 min employees
3.	Approximate expenditure on electrodes per year.	$1078/welder
4.	Approximate expenditure on wire per year.	$ 218/welder
5.	Approximate expenditure on gas per year.	$ 468/welder
6.	Approximate expenditure on welding equipment per year.	$ 622/welder
7.	Frequency of training programs for welders.	
8.	Amount of welding performed in maintenance shop.	68.4%
9.	Amount of welding performed in mine.	24.1%
10.	Amount of welding sent out.	7.6%
11.	Amount of total welding which is on low carbon steel.	61%
12.	Amount of total welding which is on high alloy steel.	23%
13.	Amount of total welding which is on irons.	5%
14.	Amount of total welding which is on stainless steel.	4%
15.	Amount of total welding which on aluminum alloys.	1%
16.	Amount of total welding which is hard facing.	6%
17.	Amount of welding performed with gas metal arc welding (MIG) in maintenance shop.	16.5%
18.	Amount of welding performed with submerged arc welding in maintenance shop.	0.8%
19.	Amount of welding performed with shielded metal arc welding (covered electrode) in maintenance shop.	72.2%
20.	Amount of welding performed with covered electrodes in mine.	77%
21.	Amount of welding performed with gas metal arc welding.	12%
22.	Fraction of welds tested by nondestructive testing technique.	≃ 0
23.	Amount of rewelding.	4.3%
24.	Fraction of maintenance cost that would be classified as welding.	15% of total cost 50% of labor cost

Your evaluation of the importance of welding research areas to be studied.	very valuable	valuable	marginal	unworthy of support
43. Proper preheating procedure for specific alloy steels used in mining industry.	X			
44. Plasma arc cutting				X
45. Corrosion of weldments			X	
46. Nondestructive testing of weldments			X	
47. Developing a welding manual for Mine Maintenance Welding of Alloy Steels.	X			
48. Proper fixturing in welding		X		
49. Proper alloy selection for maintenance welding	X			

50. If you know of a specific welding problem which you think is of the type of research that the Colorado School of Mines might perform, please describe:

Welder Training Program Outline

Session IV

Lesson 1.13) Object:
To study and demonstrate the effects of correct and incorrect polarity.

a. Determine polarity by using the carbon electrode.
b. Determine polarity by the metallic electrode (E6010).

Lesson 1.14) Object:
To study arc blow and welding with AC and DC current.

a. What is arc blow?
b. What causes arc blow?
c. How to reduce arc blow.

Lesson 1.15) Object:
To study the effects of welding heat on metals.

a. Reduce the forces which cause shrinkage.
b. Make shrinkage forces work to reduce distortion.
c. Balance shrinkage forces with other forces.

Lesson 1.16) Object:
To study electrode classification and identification.

Review questions.

A written exam with closed textbook will follow after this session covering all four previous sessions.

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13.	Amount of total welding which is on irons.	5%
14.	Amount of total welding which is on stainless steel.	4%
15.	Amount of total welding which on aluminum alloys.	1%
16.	Amount of total welding which is hard facing.	6%
17.	Amount of welding performed with gas metal arc welding (MIG) in maintenance shop.	16.5%
18.	Amount of welding performed with submerged arc welding in maintenance shop.	0.8%
19.	Amount of welding performed with shielded metal arc welding (covered electrode) in maintenance shop.	72.2%
20.	Amount of welding performed with covered electrodes in mine.	77%
21.	Amount of welding performed with gas metal arc welding.	12%
22.	Fraction of welds tested by nondestructive testing technique.	≃ 0
23.	Amount of rewelding.	4.3%
24.	Fraction of maintenance cost that would be classified as welding.	15% of total cost 50% of labor cost

		Percentage excellent	very good	adequate	inadequate	nonexistent
25.	Technical information for your welding needs from suppliers (welding and alloy) is	14	36	36	8	6
26.	Technical information for your welding needs from welding and technical journals is	0	22	53	14	11
27.	Filler materials (wire and electrodes) for mine welding applications are found to be	12	41	44	0	3
28.	Welding equipment for mine welding applications is found to be	6	43	43	6	3
29.	Availability of filler materials	3	55	42	0	0
30.	Availability of information as to the alloy content of various weldable parts of purchased mining equipment is	3	11	31	46	9
31.	Qualifications of new graduate mining engineers to handle maintenance welding problems is	0	0	23	35	42

	Your evaluation of the importance of welding research areas to be studied.	very valuable	valuable	marginal	unworthy of support
32.	Hard surfacing materials	X			
33.	Welding techniques for hard facing	X			
34.	Dissimilar metal joining		X		
35.	Semi automatic gas metal arc welding procedures and equipment for mine maintenance welding			X	
36.	Proper use of austenitic electrodes for welding alloy steel		X		
37.	Welding cast irons		X		
38.	Welding aluminum alloys			X	
39.	Welding high strength low alloy steels	X			
40.	Methods of determining economical welding practice		X		
41.	Proper weld design concepts for mining equipment		X		
42.	Electroslag welding of large sections				X

Your evaluation of the importance of welding research areas to be studied.	very valuable	valuable	marginal	unworthy of support
43. Proper preheating procedure for specific alloy steels used in mining industry.	X			
44. Plasma arc cutting				X
45. Corrosion of weldments			X	
46. Nondestructive testing of weldments			X	
47. Developing a welding manual for Mine Maintenance Welding of Alloy Steels.	X			
48. Proper fixturing in welding		X		
49. Proper alloy selection for maintenance welding	X			

50. If you know of a specific welding problem which you think is of the type of research that the Colorado School of Mines might perform, please describe:

Session IV

Lesson 1.13) Object:
To study and demonstrate the effects of correct and incorrect polarity.

a. Determine polarity by using the carbon electrode.
b. Determine polarity by the metallic electrode (E6010).

Lesson 1.14) Object:
To study arc blow and welding with AC and DC current.

a. What is arc blow?
b. What causes arc blow?
c. How to reduce arc blow.

Lesson 1.15) Object:
To study the effects of welding heat on metals.

a. Reduce the forces which cause shrinkage.
b. Make shrinkage forces work to reduce distortion.
c. Balance shrinkage forces with other forces.

Lesson 1.16) Object:
To study electrode classification and identification.

Review questions.

A written exam with closed textbook will follow after this session covering all four previous sessions.