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SURFACE PREPARATION AND COATINGS
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WELDING
INDUSTRIAL ENGINEERING
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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Reduced Volume of Spent Abrasive in Open Air Blasting

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Peterson Builders, Inc.

Report Documentation Page

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REDUCED VOLUME OF SPENT ABRASIVE IN OPEN AIR BLASTING

NSRP Project No. 3-93-6
NSRP Panel SP-3

THE FINAL REPORT

Submitted By:
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for
Avondale Industries, Inc.
Shipyards Division
July 20, 1997

FOREWORD

This research project was produced for the National Shipbuilding Research Program (NSRP) as a cooperative, cost-shared effort between the US Navy, the Maritime Administration and Avondale Industries, Inc., Shipyards Division, New Orleans, Louisiana. The Surface Preparation and Coatings Panel SP-3 of NSRP sponsored the project under the technical direction of John Meacham, Program Manager Industrial Processes.

The research was conducted at Avondale Industries' Avondale Shipyard and this final report was prepared by Avondale personnel with the assistance of H. William Hitzrot as a consultant to Avondale Shipyard. The project team wishes to acknowledge the following Avondale personnel for their assistance in conducting this project:

- Mr. Frank Munger, Vice President
- Mr. Charles Bourg, Sr., Paint Superintendent
- Mr. Ernie Miguez, Assistant Paint Superintendent
- Mr. Buddy Cusimano, General Foreman, Paint Department
- Mr. Gilbert Arceneaux, General Foreman, Paint Department
- Mr. Glenn Clement, General Foreman, Paint Department

The project team also wishes to acknowledge the many Avondale employees who contributed not only their time but also their ideas which contributed to the success of this project.

The project team would also like to thank the following companies who contributed time, material and equipment to the project:

- Barton Mines
- Chesapeake Specialty Products
- Environmental Containment Systems
- Schmidt Manufacturing
- Stan Blast Abrasives
- Ingersol Rand
- Marco

Executive Summary

Shipyards have been blast cleaning ships for more than 50 years. The methodology is still basically the same but numerous improvements have taken place over the years. The purpose of this project is to look at current blast cleaning technology, review what is being done by U. S. shipyards and define a strategy that will not only reduce the amount of abrasive being used for blasting operations but also increase shipyard blast cleaning productivity.

At the outset, four shipyards were visited and the blast cleaning operations at each yard reviewed. It became readily apparent at the conclusion of these shipyard visits that all four yards face similar problems in the area of blast cleaning; be it new construction or ship repair. The findings from these visits were as follows:

- The major source of over consumption of abrasives is improper adjustment of the valves metering abrasive to the blast nozzle. The use of metering valves on all blast pots and the proper adjustment of these metering valves can reduce abrasive consumption by up to 30 percent.
- Proper use and matching of air pressure, type of abrasive, hoses, nozzles can increase productivity and therefore reduce abrasive consumption.
- Vacuum-blasting and/or power tool cleaning may offer an abrasive saving alternative in new construction during final erection and cleaning of master butt welds and abrasions.
- Effective blaster training programs are lacking at most yards. There is a need for an effective blaster training program to instruct blast cleaning personnel on how to be more productive through proper use of equipment, air pressure and abrasive.

The major findings noted above formed the basis for the project's initial research program. This program was augmented with the study of abrasive recycling and the study of equipment improvements that would further contribute to reducing abrasive consumption.

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CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:
The findings from this study are based on limited testing generally under shipyard conditions. The findings summarized below are based on the tests conducted at Avondale, the results therefore will vary from yard to yard. However, the trends indicated by the Avondale study should be the same for all yards when using the test protocols noted in the study.

A summary of the conclusions from this study follow:

- Shipyards can make significant reductions in abrasive consumption through the use of abrasive metering valves. Changes as small as a half turn on the metering valve can increase abrasive consumption by 50% with little or no improvement in productivity. Calibrating the metering valves to the abrasive being used is absolutely essential.

- Abrasive recycling is best suited to steel abrasives and, when using steel abrasive recycling, can reduce abrasive consumption by 90% or more.

- Non-metallic abrasives are less well suited for recycling because of the high breakdown rate, 25% or more per cycle, and increased abrasive dust load in the work mix when using recycled grit.

- Elevated nozzle pressures offer major savings in abrasive consumption by increasing productivity by as much as 300% and, at the same time, **reducing** abrasive consumption by as much as 45%.

- Consistent productivity improvements can be assured only through regular monitoring of nozzle pressure, nozzle wear, abrasive quality and blaster training.

The findings resulting from the research and testing portion of the study demonstrated that shipyards can significantly reduce abrasive consumption, from 45%, to 90%, by incorporating one or more of the following:

- Abrasive metering
- Use of elevated nozzle pressures
- Recycling

Using any or all of these approaches will more than meet the project goal of a 15% reduction in abrasive consumption.

As part of the project deliverables, a set of process control standards and operating procedures are provided covering the setting of metering valves, evaluating abrasives, nozzles and nozzles pressure. These protocols are presented in the report and will allow other yards to use the information to optimize their blasting operations.

In addition to the major abrasive savings discussed above, this study uncovered numerous smaller, yet no less effective, ways to reduce abrasive consumption. A number of these ideas were worker suggested.
A summary of the subjects covered under **Part 2** of this study are listed below:

- Vacuum-blast as a specialized tool
- Metering valve quick disconnect
- Flexible, large diameter whip hose
- Specialized containment equipment
- Nozzle selection

Each of these items is discussed under **Part 2** with examples to demonstrate how the specialized tool or methodology can create a major reduction in abrasive consumption. The significance of this portion of the report is to demonstrate how simple changes in approach to a blast cleaning job or incorporation of new technology can provide the necessary reduction in abrasive consumption. It points the need to be open to new approaches, not resist change and use periodic training programs to assure that the blaster and supervisor use, and are comfortable with, the most productive surface preparation methods.

RECOMMENDATIONS:
The key finding from this project is the need throughout the shipyard industry for a comprehensive blaster training program. The primary thrust of this program would be to demonstrate to blasters how blast cleaning productivity is influenced by such key parameters as the type of abrasive used, abrasive metering, nozzle pressure, nozzle size, nozzle type to name a few. Training is the only way to give the person at the blast nozzle the knowledge he needs to do his job successfully.

The training outline submitted with this project is a beginning. It is recommended that this project be augmented to include development of a complete blaster training program for use throughout the shipyard industry.

PART 1
DATA GATHERING AND PROCESS IMPROVEMENT

Task 1: Information Gathering

The first step in the development of this project is to review current surface preparation techniques used in shipyards around the country as well as in other industries. This section discusses visits made to three representative shipyards to review how these yards handle surface preparation in general and open air blasting in particular. A questionnaire (see Attachment I at end of Task 1) was used for each visit and the responses to the questionnaire are summarized in Table 1-1. General conclusions drawn from these shipyard surveys are listed below along with the shipyards that participated:

- All yards surveyed are experiencing similar problems with open air blasting, and all are trying to find ways to cope with these problems.
- Typical open air blasting problems include; control of dust emissions, varied abrasive consumption rates, excessive abrasive disposal costs

Shipyard	Location	Date
NASSCO	San Diego, CA	12/14/94
Southwest Marine	San Diego, CA	12/15/94
Bath Iron Works	Bath, ME	1/12/95
Avondale Industries	New Orleans, LA	Sponsoring Yard

Survey findings that warrant further evaluation:

- Abrasive metering valves on blast pots have demonstrated as much as a 30% savings in abrasive consumption.
- The use of whip hoses on the end of blast hoses reduce blasting efficiency and thus increase abrasive consumption. Whip hoses should be restricted to blasting in confined spaces.
- Power tool cleaning should be used extensively in new construction where there is minimum area to be cleaned.
- Initial testing of garnet abrasive at Bath Iron works produced encouraging results, i.e. less dust, and fewer man-hours blasting. Additional testing is required to determine if the cost savings are worth the relatively higher abrasive cost.

Table 1-1
Blasting Operation Survey Summary

Equipment	NASSCO	Southwest Marine	Bath Iron Works	Avondale Industries
Blast Pots	8 ton Key units	2 x 28 ton Key units 1 x 51 ton Key 8 valve units	6 x 8 ton key units 1 x 22 ton Key units 3 x 40 ton Key units	6 x 600 lb 1 valve units 2 x 6 ton mobile units 11 x 20 ton, 6 valve units 12 x 40 ton, 8 valve units 2 x 42 ton, 8 valve units, double chamber
Pot Valves	1¼ Ball Valves	1¼ Ball Valves	Schmidt MicroMeter Valve	Schmidt MicroMeter Valve
Air Pressure: at Pot at Nozzle	 100-110 psi 65-80 psi	 110 psi 90 psi	 125 psi 100 psi	 125 psi 100 psi
Hoses: Inside Diameter Length	 1½ inch 100 ft	 1½ inch 300-350 ft	 1½ 50-250 ft	 1¼, 1½, 2 inch 150-250 ft
Whip Hose Diameter	¾ and 1 inch	1 inch	1 inch	¾, 1¼, 1½ inch
Nozzles	#7 and #8	#6 and #7	#6, #7, and #8	#7 and #8
Abrasives Used	Steel grit Copper Slag Garnet Aluminum Oxide	Garnet Copper Slag	Steel Grit Coal Slag Walnut Shells Garnet	Steel Grit Coal Slag Mineral Grit Aluminum Oxide
Vacuum System	Key liquid ring vacuum	Portable ECS vac pumps	IPEC recovery units	Liquid ring and vac trucks
Vacuum-blast Systems	None	None	None	Under Development
Blaster Training	Formal program with utility tank mock-up to establish blaster classification	Utilizes SUPSHIP training and classification manual	None	Under Development

A more detailed summary follows covering each of the five areas of interest; Equipment, Abrasives, Vacuum Systems, Vacuum Blast Systems and Training.

<u>Equipment Survey of the Yards Visited</u>

Abrasive Metering: Blast pots of various sizes are typically fitted with 1_ inch ball valves to manually control abrasive consumption. Both Avondale Industries, Inc. (AII) and Bath Iron Works (BIW) have replaced the ball valves with Schmidt Manufacturing's MicroMetering valves. These valves offer much more precise metering of abrasive to the blast nozzle, reducing abrasive consumption and increasing productivity. BIW reported as much as a 30% savings in abrasive consumption when the valves are properly adjusted. Details on the valves description and adjustment procedures will be discussed under Task 2, Experimentation. The valves are costly but, based on BIW's experience, worth the $250 per valve price.

Air Pressure: There were wide variations in nozzle pressures used at the different yards due to varying demands and the variety of installed systems. It was generally agreed however, that the optimum nozzle pressure is 100 psi at the nozzle which requires about 125 psi at the compressor. Shipyards are well aware that contractors doing blasting in a shipyard will provide their own compressors in order to be assured of sufficient air pressure during blast cleaning. Tests conducted by Schmidt Manufacturing have shown that a reduction of 1 psi reduces productivity by 1 1/2%. Avondale did some testing and the results corroborate the importance of nozzle pressure and productivity. These results will be discussed in detail under Task 2 Experimentation.

Blast Hose: All yards visited use essentially the same diameter blast hose. Only the length varies with distance to the work site. The use of whip hoses is also quite common but whips do reduce blast nozzle pressure and thus reduce productivity. In general, the use of whips should be discouraged except in areas of tight angels, T beams and areas were accessibility is difficult. An exception to this general rule is the use of Hi-Flex whip hose. The hose is described in more detail in Part 2 Task 3.

Abrasives : A wide variety of abrasive media is currently in use at the three yards visited. Often the type of job will dictate the type of abrasive used. For example BIW, NASSCO and AII preblast and prime the steel as it comes into the yard. Preblasting is generally done using steel abrasives where the abrasive is recycled thus minimizing waste and disposal. After fabrication into subassemblies, these units are reblasted most often in a large blast room, again using steel abrasive to minimize waste. BIW has found that by using this technique, a major portion of additional blast cleaning can be replaced with hand tool cleaning of the master butt welds reducing abrasive consumption and disposal costs.

Southwest Marine (SWM) uses copper slag abrasive for most of its blast cleaning and contains blast cleaning dust and debris through extensive use of shrink wrap containment. This approach solves the dust problem but does not minimize abrasive consumption, waste and disposal.

A number of yards are using or experimenting with garnet abrasives as a means to improve productivity, and reduce waste. AII has conducted similar tests and will review the results in Task 2. BIW has evaluated garnet abrasives and a report covering their results is provided in Attachment II at the end of Task 1. The conclusions from the BIW findings are quoted below:

> "In conclusion, blasting with garnet in comparison to coal slag produced a significant decrease In the visible airborne emission, and eased the effort to attain compliance with the opacity limitation in the Air Emission License. Newer and properly maintained equipment produced a noticeable decrease in emissions also."

Abrasive Clean-Up and Recovery: Each yard has adapted its own method of abrasive recovery suited to its needs as outlined below:

- SWM: Southwest Marine uses one small, portable ECS (Environmental Containment Systems, Inc.) vacuum pump to recover abrasive.
- BIW: Bath Iron Works uses IPEC vacuum recovery systems throughout the yard. Much of the on-board surface preparation is being done by power tool cleaning of the master butt welds and damaged areas. This method greatly reduces abrasive usage, handling and clean-up costs but requires production scheduling and painting that allows complete fabrication and painting of subassemblies prior to erection.
- NASSCO: National Steel and Shipbuilding uses liquid ring water vacuum systems throughout the yard for their abrasive clean-up and recovery. The yard experimented with vacuum trucks but were not satisfied with the system's performance.

- AII: Avondale uses a combination of liquid ring vacuum systems and vac-trucks for their grit clean-up and recovery. No non-metallic abrasive recycling is currently being done with the vacuum clean-up and all used abrasive is sent to landfill.

Abrasive Disposal: Disposal of used blast cleaning abrasive is a common problem for all yards visited. Each yard is using a different solution as outlined below:

- NASSCO: Spent abrasive is screened to remove non abrasive debris and sent to cement plants at a cost to NASSCO of more than the original cost of new grit.
- BIW: Spent coal slag abrasives only are sent to a cement plant (no cost available) all other waste abrasives are sent to solid waste disposal.
- SWM: Used copper slag abrasives are sent via railcar to cement plants.
- AII: Avondale currently disposes of non hazardous, used blast cleaning abrasive debris in a landfill at around $3.00 per cubic yard. Disposal of hazardous waste is much more costly.

Vacuum-blast Systems: The use of vacuum-blast systems by shipyards is not universal. BIW for example, uses hand tools instead of vacuum-blast units. Only AII uses these systems extensively as described below.

- SWM: Southwest Marine does not use any vacuum-blast systems.
- BIW: Bath Iron Works likewise does not have any vacuum-blast systems at this time.
- NASSCO: National Steel and Shipbuilding likewise does not use vacuum-blast systems because they found vacuum-blasting to be too slow with low productivity.
- AII: Avondale has several vacuum-blast systems that recycle abrasive and are used occasionally but the production rates for these units are very slow.   Avondale is experimenting with specially designed vacuum-blast systems for special applications. The concept offers two major attributes relating to this project; abrasive containment and recycling. The results of the Avondale experiments will be reported under Part 2.

Training Program: Each yard has adapted some form of training, but none of the yards has developed a complete program. The programs currently in use are outlined below:

- SWM: Southwest Marine uses a training manual written by the U. S. Navy's Repair Engineering Branch for blaster and painter certification.
- BIW: Bath Iron Works does not have any blaster and painter training program in place at this time. However, BIW is considering an Industrial Training Manual for blasters and painters.
- NASSCO: National Steel and Shipbuilding has a training program in place for blasters and painters. The program uses a tank module for testing all blasters upon hiring for classification purposes. NASSCO also uses the training program to teach the best methods of blasting and uses a two year training program for advancement.

TASK 1 CONCLUSIONS

The shipyard survey showed that all four yards face similar problems in the area of blast cleaning. The primary problem areas are; blaster training, abrasive consumption rates, dust emissions and abrasive disposal. Some key areas were identified where significant improvements can be realized and these areas are cited below:

- The major source of over-consumption of abrasives is improper adjustment of the valves metering abrasive to the blast nozzle. The use of metering valves on all blast pots and the proper adjustment of these metering valves can reduce abrasive consumption by up to 30 percent.
- Proper combination of air pressure, abrasive, hoses and nozzles can increase productivity and therefore reduce abrasive consumption.
- Vacuum-blasting and/or power tool cleaning may offer an abrasive saving alternative in new construction during final erection and cleaning of master butt welds and abrasions.
- Effective blaster training programs are lacking at most yards. With an effective training program blasters can be instructed on how to be more productive through proper choice and use of equipment, air pressure and abrasive.

The four key areas cited above will be the main focus of study and research for this project.

Attachment I

Shipyard Blaster Survey Questionnaire

Date of Visit:
____

Name of Shipyard Visited: ______________________________________

Types of Blasting Equipment Used: _______________________________

Types of Abrasive Used: ______________________________________

Types of Vacuum systems Used: _________________________________

Types of Vacuum-blast Systems Used: ____________________________

Blaster Training Programs Used: _________________________________

Attachment II

Karen Morrison
December 23, 1994
KBM940023

Blasting Operations
Environmental Comparison of Garnet vs. Coal Slag

On November 30, 1994 a test was conducted using GMA Garnet as a blast media on the forward section of Hull 458. On December 2, 1994, coal slag (Black Beauty) was used. This enabled a comparison to be made of the two different blasting materials. (Note: This test was conducted with one blaster only.)

Visible emissions from blasting operations are in the form of fugitive particulate matter from paint chips and spent blast media. Bath Iron Works, Bath Facility is currently waiting for an amendment to the Air Emission License to increase the visible emission limit from 0% opacity to 20% opacity with a 5 minute exemption in any one hour. This limit pertains to fugitive emissions that occur outdoors.

From an environmental stand-point, the garnet was a significant improvement over coal slag. Visible emissions generated from the garnet blasting averaged about 15%-25% opacity under the enviroscreen. Visible emissions outside of the enviroscreen were minimal (<5% opacity). The coal slag created continuous emissions of approximately 50%-60% opacity. Even with the enviroscreen enclosing the operations, emissions outside of the enclosure ranged from 15%-25% opacity continuously, with several occurrençes of higher opacity. Operations were stopped at one point to allow emissions to settle and/or disperse in an effort to stay within compliance of the air emission requirements of our license.

During the testing two different nozzles were also employed, a new venturi type 7 and a worn size 8 venturi nozzle. An obvious improvement in emissions was also noted with the new type 7 nozzle.

In conclusion, blasting with garnet in comparison to coal slag produced a significant decrease in the visible airborne emissions, and eased the effort to attain compliance with the opacity limitation in the Air Emission License. Newer and properly maintained equipment produced a noticeable decrease in emissions also.

Part 1, Task 2: Experimentation and Data Gathering
This task covers a series of trials using several different types of abrasive to test various methods of reducing abrasive consumption. The abrasives used were garnet, staurolite, coal slag and steel abrasive. The methods evaluated included metering valves, abrasive recycling equipment, various blast nozzle designs and elevated nozzle pressures. Some of the test work was conducted under actual shipbuilding blast cleaning conditions.

A summary of the results from Task 2 follows:
- Schmidt Micrometering valves offer significant savings in abrasive consumption when properly adjusted.
- It is possible to increase productivity and reduce abrasive consumption using micrometering valves and a simple test procedure is outlined to establish optimum abrasive flow.
- Non-metallic abrasive recycling was found to be impractical because of excessive dust and fines which result with each successive recycle. The increase in dust and fines caused reduced visibility and productivity.
- Metallic abrasive can be recycled 50 or more times reducing abrasive consumption by 90% or more.
- Improved blast nozzles offer higher productivity which in turn reduces the amount of abrasive required to accomplish the same amount of work. For example; a Bazooka #8 nozzle has more than twice the production rate (527ft^2 per hr) compared to a double venturi nozzle (257ft^2 per hr) when run at the same nozzle pressure.
- Nozzle pressure offers another method of reducing abrasive consumption. Combining higher nozzle pressures (125-155 psi) and finer abrasives (G-50 or G-80 steel grit) cleaning rates in the range of 500 ft^2/hr can be achieved compared to the more typical 130 ft^2/hr at 90/100 psi. Also, abrasive consumption is reduced to less than 4 lb. per ft^2.

The discussion that follows describes the test procedures used to develop the findings cited above. Recommended test procedures are outlined that can be used by shipyards to evaluate their own abrasive blast operations.

<u>Micrometering Valves:</u> A micrometering valve permits accurate control of abrasive flow and that flow can be established by counting the number of turns on the metering valve. A cross section of a typical metering valve is shown in Figure 1-1.

Figure 1-1
Cross-section of a typical Schmidt MicroValve showing how turning the control knob can accurately meter the abrasive flow into the air stream.
(Courtesy Schmidt Manufacturing)

The initial metering valve tests were conducted using two different abrasive products; heavy Black Beauty and Star Blast, and two different abrasive metering valves; a Key #100 metering valve and a Schmidt MicroValve. The tests showed that Schmidt MicroValves can reduce abrasive consumption but productivity was reduced compared to the Key #100 valve, see Table 1-2 below.

Table 1-2

Initial Metering Valve Test

All Tests Run at 95-100 PSI at the Nozzle

Test Parameter	Type of Abrasive Used			
Abrasive	Heavy Black Beauty		StarBlast	
Metering Valve	Schmidt	Key	Schmidt	Key
Area Blast Cleaned	160 ft^2	160 ft^2	160 ft^2	160 ft^2
Abrasive consumed	360 lb	920 lb	300 lb	1020 lb
Time	38 min	21 min	26 min	21 min
Cleaning rate	252 ft^2/hr	456 ft^2/hr	372 ft^2/hr	456 ft^2/hr
Abrasive Consptn rate	9.5 lb/min	44 lb/min	12 lb/min	49 lb/min

It was apparent from these test results that the optimum grit flow had not been achieved. After consultation with the manufacturer of the Schmidt valve, Avondale conducted a new series of tests incorporating several different abrasive flow settings with the idea of bracketing the optimum flow rate. The tests were run using four different abrasive products as follows: fine coal slag, StarBlast, Aluminum oxide and Steel abrasive. An excerpt from the test results is shown in Table 1-3 and illustrates the importance of abrasive metering.

Table 1-3

Abrasive Metering Trial

Using fine coal slag

Abrasive Flow lb/ft^2	Production Rate ft^2/hr
3.1	324
3.5	**360**
6.6	252

It is apparent from the data shown in Table 1-3 above that choosing the proper flow rate can make a significant improvement in productivity and can significantly reduce the amount of abrasive used. In this case (see bold numbers in Table 1-3) at a flow rate of 3.5 lb/ft^2 the optimum productivity of 360 ft^2/hr was achieved. Increasing the flow beyond the optimum results in a major reduction in productivity even though the amount of abrasive used almost doubled. This all points to the need for careful supervision of abrasive flow during blasting to minimize abrasive consumption and achieve maximum productivity.

Metering valve tests run on different types of abrasive showed that for each size, type of abrasive and nozzle pressure, a different meter valve setting is required to achieve optimum productivity with minimum abrasive consumption. It was also determined that increasing abrasive flow can show increased productivity but only with excessive abrasive consumption, as illustrated in Table 1-4 below.

Table 1-4

30/60 Garnet

MeterValve	Cleaning Rate	Grit Application Rate	
# of Turns	ft^2/hr	lb./hr	lb/ft^2
2	73	344	4.7
2.5	218	736	3.4
3	232	1327	5.7
3.5	234	1407	6.1
4.5	263	2803	10.7

From Table 1-4 above, note that when the metering valve is opened 1/2 turn, from 2 to 2.5, the cleaning rate increases 3 times from 73 ft^2/hr to 218 ft^2/hr. When the meter valve is opened to 3 the cleaning rate increases a little, from 218 ft^2/hr to 232 ft^2/hr but the grit consumption doubles, from 736 lb/hr to 1307 lb/hr. The data in Table 1-4 also shows that this trend continues, additional small increases in meter valve opening result in large increases in abrasive consumption with little increase in productivity. Since abrasive clean-up averages 50% or more of the time it takes to blast clean, these small increases in blast cleaning productivity are more than offset by much larger abrasive clean-up costs. The optimum valve setting therefore, is about 2.5 turns which provides excellent productivity with minimum abrasive consumption.

Abrasive Recycling

Non Metallic Abrasives: Historically, non-metallic abrasives are used once and discarded. Recycling of non-metallic abrasives offers the greatest opportunity to reduce the amount of abrasive used and sent for disposal. Earlier attempts to recycle non-metallic abrasives including a MARAD study done in 1987 (Ref. 1) have not proven economical or feasible in shipyards. However, Avondale decided to revisit this concept because it is potentially the best opportunity to reduce abrasive usage.

Garnet was chosen as the abrasive for the recycling trial and the test was run in conjunction with Barton Mines using GMA garnet. A production environment was established for the test and involved spot blast and sweep blast around weld seams and mechanically damaged areas on seven internal tanks of a newly constructed U. S. Navy TAO Tanker prior to painting. This test did not include complete tank blast cleaning to remove all coatings.

The initial recycling results looked encouraging enough that the yard decided to run a garnet recycle test on an entire cargo tank. The used garnet generated during the recycling trial was collected, reprocessed at a near-by facility and the recycled garnet was then blended with new garnet for reuse. Over 100,000 ft^2 were blast cleaned using a blend of new and recycled garnet. A total of 120 tons of new garnet was used along with 200 tons of recycled garnet. Without recycling, garnet required an average of 3.75 pounds of garnet per square foot blast cleaned. With garnet recycling the amount of abrasive consumed was 1.4 pounds per square foot, reducing abrasive consumption and disposal by 62%.

The major problem with recycling garnet is that with each succeeding cycle the garnet mix became more dusty and less productive. Recycling non-metallic abrasives therefore, did not prove to be a viable method of reducing abrasive consumption because of the resulting productivity decrease.

Steel Grit Recycling in Tank Blasting: There are two major concerns when using and recycling steel abrasives for on-board tank blasting. They are; how to keep the steel grit from getting wet, and can steel grit be vacuumed with existing yard vacuum equipment?

Recent tests at Avondale experimented with the use of steel grit for on-board tank blasting to evaluate these two key issues; moisture and vacuuming. The results were encouraging. The test used an Environmental Containment Systems (ECS) abrasive recycling unit equipped with a positive displacement vacuum.

The combination of excellent visibility during blasting coupled with high productivity when using fine (G-50) steel grit resulted in production rates in excess of 400 ft^2 per hour using about 3.5 lb of steel grit per ft^2. The test was run during high humidity and frequent afternoon rain showers. Even with condensing moisture and high humidity no grit was lost to moisture. No problems were encountered even when vacuuming from inside the tank which was over 100 feet from the vacuum recovery and recycle unit. More than 98% of the grit was recovered cleaned and returned for reuse. Table 1-5 shows the screen analyses of samples taken during the steel grit tank blasting test. Note, from the data shown in Table 1-5, little break down of the abrasive occurred with virtually all of the abrasive being recovered for reuse.

Table 1-5

Sieve Analysis New and Used G-50 Steel Grit from #4 Tank Test

Mesh Size	New G-50 Steel Grit	Used Grit After Classifier
	Cumulative Weight %	
25	<1	<1
30	1	3
40	77	72
50	99+	94
70	99+	98
100	-	99+
Pan	100	100

<u>Blast Nozzle Tests</u>

There are a number of newer nozzle configurations on the market which may offer some improvement in productivity and thus reduce abrasive consumption. Two new nozzles, the Bazooka nozzle and the Double Venturi nozzle were tested and compared with the standard venturi nozzle as part of this study. The Bazooka nozzle gives a larger blast pattern because of the exit bore shape, but requires a minimum of 100 psi at the nozzle to realize the nozzles full potential. In general the Bazooka nozzle will out perform all other nozzles when blasting at 100 psi and higher. The Bazooka nozzle has two major advantages, it provides excellent coverage and minimizes back pressure on the blaster, making blasting at elevated nozzle pressure less fatiguing and therefore more productive.

The Double Venturi nozzle also offers the advantage of being less fatiguing on the blaster at elevated nozzle pressures compared to conventional venturi nozzles. However, the double venturi nozzle was not as productive as the Bazooka nozzle.

Using newer nozzle designs can reduce abrasive consumption by making each pound of abrasive more productive during blasting. A study is being conducted at Penn State University as a research project in the University's Gas Dynamics Laboratory. Preliminary results on this study were reported in the October 1996 issue of The Journal of Protective Coatings and Linings. In summary, the preliminary results of Gary Settles' Penn State Study have demonstrated a 35% increase in abrasive particle exit velocity compared to conventional venturi nozzles with a goal of doubling the exit velocity of the current venturi nozzles. It is evident from this study that nozzle design has a major impact on abrasive consumption and productivity, and emphasizes that nozzle selection is an important part of planning a job.

Testing Nozzle Pressure and Nozzle Diameter

When evaluating blast cleaning equipment it is important to be able to measure two key parameters, pressure at the nozzle and nozzle wear. The standard tests for nozzle pressure and nozzle wear are the needle pressure gauge to test air pressure at the nozzle and the nozzle aperture gauge to check nozzle diameter. Both of these tools are shown in Figure 1-1. The air pressure at the nozzle should be checked regularly to assure sufficient air pressure. The nozzle aperture gauge should also be used regularly to check for nozzle wear. The procedures for testing will be covered in the training portion of this study. Maintaining sufficient nozzle pressure and maintaining proper nozzle diameter assures efficient use of abrasives and therefore, reduced abrasive consumption.

Elevated Nozzle Pressure Study

Increasing nozzle pressure offers the greatest potential for increased productivity and therefore reduced abrasive consumption. A series of tests using the procedure outlined under Part 1 Task 3, Abrasive Evaluation, were run first using compressed air from the yard distribution system and then rerun using a dedicated compressor capable of 160 psi at the compressor. The results from these tests clearly show that higher pressures are more productive. A summary of the test results are given in Table 1-6 below.

Table 1-6

Nozzle Pressure Affects On Cleaning Rate

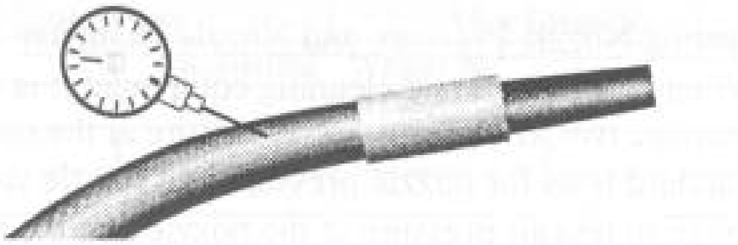
Using Steel Grit and a #8 Bazooka Nozzle

Steel Grit Size	G-50	G-50	G-80
Nozzle Pressure (psi)	**75**	**155**	**155**
Production Rate (ft^2/hr)	175	527	535
Abrasive Usage (lb/ft^2)	5	6.6	3.6

It is evident from these results that increasing nozzle pressure makes a significant, 300%, increase in productivity; going from 175 ft^2/hr to 527 ft^2/hr.

Use of Hypodermic Needle Pressure Gauge

- *Start up the blast operation with nozzle functioning.*
- *Insert the needle approximately 12" behind the blast nozzle. The tip of the needle should be slanted toward the nozzle to avoid it from becoming clogged with abrasive.*
- *Read and record the gauge pressure.*
- *Can be used to trouble shoot entire blasting systems for pressure drop.*



Use of the Blast Nozzle Aperture Gauge

- *Use the provided china marker to mark the gauge lengthwise. Remove nozzle and insert gauge as illustrated at right.*
- *Remove the gauge and note the point where china marker was removed by contact with the nozzle.*
- *Read the scale number on the gauge corresponding to that mark. This is the nozzle aperture size in sixteenths of an inch. The CFM required for this nozzle size is also noted.*
- *Recommend disposal of Venturi nozzle when diameter increases by 1/16".*

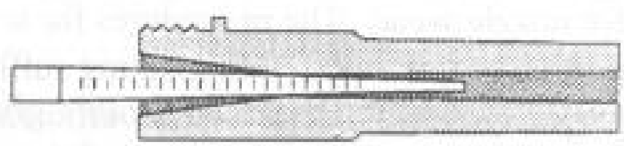


Figure 1-2

Nozzle pressure gauge tester and nozzle aperture gauge.

(Courtesy S. G. Pinney & Associates, Inc.)

Also at these higher (125-150 psi) nozzle pressures it is possible to use finer abrasive particles, in this case G-80 grit. By using finer abrasives, the test showed that abrasive consumption per square foot was reduced 45%, from 6.6 lb/ft^2 to 3.6 lb/ft^2.

Increasing nozzle pressures to 125 psi or higher offers one of the easiest ways to both decrease abrasive consumption by 20-45% and increase productivity by 100% or more.

Screen Analyses of the Abrasive Products Tested

The screen analyses of all the abrasive products tested in this report are shown in Table 1-7 on the next page. The table illustrates the wide variety of size distributions and the diverse types of abrasive products available to the shipyard. With this diversity comes the need to evaluate and choose the right product for the job.

Summary Experimentation and Data Gathering

The results of this task have shown that there are a number of opportunities for shipyards to make significant reductions in abrasive consumption. The greatest savings in abrasive consumption can be accomplished by adapting control of abrasive consumption through the use of abrasive metering valves, and calibrating the metering valves to the abrasive being used.

Abrasive recycling was tested using both metallic and non-metallic abrasives. The test results showed that recycling steel abrasive can reduce abrasive consumption by 90% or more, while non-metallic abrasives proved to be unsuited to recycling. The recycling tests of non-metallic abrasives showed a 25% breakdown rate, high dust levels in the recycled abrasive and reduced productivity with each recycle.

Elevated nozzle pressures, as this study showed, offer major savings in abrasive consumption by increasing productivity as much as 300%. These productivity improvements can be enhanced by regularly checking nozzle pressures, nozzle wear and using newer nozzle designs.

Table 1-7
Screen Analyses of Abrasive Products Tested

Sieve Size	Coal Slag Coarse	Coal Slag Fine	StarBlast	Garnet	Garnet 30/60	Aluminum Oxide	Glass-Blast	Steel Grit G-50	Steel Grit G-80	Sieve Size
	Cumulative Weight %									
8	4	-	-	-	-	-	-	-	-	8
10	11	-	-	-	-	-	-	-	-	10
12	-	-	-	-	-	-	<1	-	-	12
16	59	-	-	-	-	<1	13	-	-	16
18	-	-	-	-	-	20	-	-	-	18
20	87	11	-	-	-	60	42	-	-	20
25	-	-	-	-	-	88	-	-	-	25
30	97	19	<1	<1	2	94	59	4	-	30
40	99+	38	3	7	20	99+	75	77	<1	40
50	-	-	16	55	65	-	87	98	66	50
60	-	70	-	-	85	-	93	-	97	60
70	-	-	41	90	93	-	97	99+	99+	70
80	-	85	-	99	-	-	-	-	-	80
100	-	-	77	-	-	-	-	-	-	-
120	-	94	-	99+	97	-	-	-	-	120
140	-	-	95	-	-	-	-	-	-	-
200	-	-	98	-	-	-	-	-	-	-
270	-	-	99+	-	-	-	-	-	-	-
PAN	100	100	100	100	100	100	100	100	100	PAN

Part 1 Task 3

Developing Process Control Standards and Operating Procedures to Reduce Abrasive Consumption

The results of a number of tests were reported under Task 2. This section will outline the test parameters used to develop these results and will recommend the test procedures that can be used to:

- Determine proper abrasive metering valve settings,
- Evaluate types of abrasives,
- Evaluate types of nozzles,
- Evaluate nozzle pressure effects.

The purpose of these tests is to reduce overall abrasive consumption and increase productivity.

Abrasive Metering

Discussions with metering valve manufactures revealed that there is no standard setting for metering valves that covers all abrasives. The initial task therefore, was to develop a standard metering valve setting procedure. Avondale, after numerous trials with a variety of abrasives, developed a procedure that establishes the optimum setting for any given abrasive. The procedure developed is outlined below:

1. Start with a known weight of abrasive, for example 50-60 lb.
2. Place the 50 lb abrasive sample in a 300 lb blast pot fitted with a metering valve (see Figure 1-3).
3. Scribe the surface to be blast cleaned into 1 square foot segments, see Figure 1-4, for ease in measuring the total area blast cleaned.
4. Close the meter valve and then open meter valve 2 turns.
5. Use a minimum 100 psi air pressure at the nozzle.
6. Record the time to blast clean a measured area using the entire abrasive charge.
7. Blast clean the surface to a standard degree of cleanliness, i.e. SSPC SP 5.
8. Repeat steps 1-7, using the same weight of abrasive, at metering valve settings of 3 turns and 4 turns.
9. Compare the productivity (square feet per minute blast cleaned) Vs abrasive consumption (pounds abrasive per square foot blast cleaned) at the three different metering valve settings (2,3 and 4 turns) and fine tune with 1/2 turns to achieve optimum setting.

Figure 1-3: Blast Pot, 300 lb capacity, and fitted with metering valve.

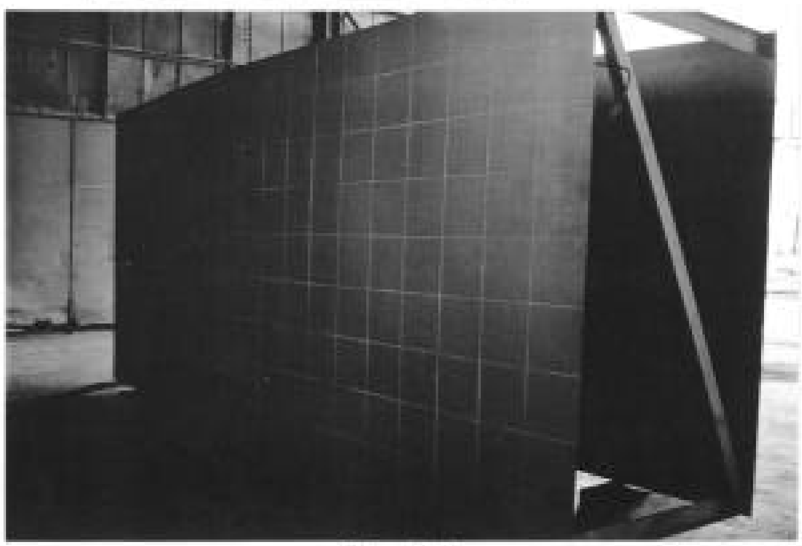


Figure 1-4
Test Plate set-up for evaluating abrasives and metering valve settings

Using the abrasive metering test procedure outlined above, a series of abrasive evaluations tests were performed to establish how various abrasive types affect metering valve settings. These results are shown in Table 1-8. The results show that small changes in metering valve turns can produce large changes in abrasive consumption. It is also evident that there is no single metering valve setting that fits all abrasives because abrasive metering is affected by particle shape, size, and density as well as nozzle pressure. However, as the data indicates, a setting of 3 turns on the metering valve

Table 1-8
Metering Valve Test Data

Abrasive Type	**Meter Valve** turns	**Metering Rate** lb/min abrasive feed	**Productivity** ft^2/hr blast cleaned	**Application Rate** lb/ft^2 abrasive used
Fine Coal Slag	2	16.8	338	3.0
Fine Coal Slag	3	21.0	360	3.5
Fine Coal Slag	5	27.6	256	6.5
StarBlast	2	12.0	270	2.7
StarBlast	3	30.6	412	4.4
StarBlast	5	38.4	400	5.8
Aluminum Oxide	2	14.1	129	6.5
Aluminum Oxide	3	28.5	216	7.9
Aluminum Oxide	5	70.2	338	12.4
G-50 Steel Grit	2	11.8	126	5.6
G-50 Steel Grit	3	30.2	222	8.2
G-50 Steel Grit	3.5	38.0	213	10.7
G-50 Steel Grit	4.5	43.3	219	11.8
Garnet	2	5.7	73	4.7
Garnet	2.5	12.3	218	3.4
Garnet	3	22.1	232	5.7
Garnet	3.5	23.4	234	6.1
Garnet	4.5	46.7	263	10.7
Glass Blast	2.75	16.8	215	4.7
Glass Blast	3	21.9	250	5.3
Glass Blast	3.5	25.2	333	4.5
Glass Blast	4	39.7	333	7.2

should bring the operator close to the optimum and the operator can fine-tune by half turns for optimum productivity and abrasive consumption.

An abrasive evaluation form has been established based on the abrasive evaluation procedure used to develop the data for Table 1-8 and this form is included as Attachment III. A form, such as shown in Attachment III, should be used when evaluating abrasives.

To determine the optimum metering valve setting, choose the setting that gave the best productivity with the least abrasive consumption. For example, look at Table 1-8 which summarizes the results conducted at Avondale. The optimum setting for each abrasive is highlighted in the table and the results are discussed below.

- Fine Coal Slag: For the Fine Coal Slag the optimum metering rate is about 21lb/min at 3 turns on the metering valve and with productivity peaking at 360 ft^2/hr. Note that opening the metering valve to 5 turns resulted in a 31% increase in abrasive consumption and 28% reduction in productivity.
- StarBlast: For StarBlast the productivity change is not as dramatic. Increasing abrasive feed, going from 3 turns to 5 turns on the metering valve, showed no increase in productivity but increased abrasive consumption by 32%. Clearly, increased StarBlast consumption offers no benefit.
- Aluminum Oxide: The results for Aluminum Oxide were less clear with good productivity being achieved at very high, 70 lb/min metering rates and 5 turns on the metering valve. In this case it may be better to sacrifice productivity to reduce consumption.
- G-50 Steel Grit: For G-50 Steel Grit it appears that the metering valve setting of 30.2 lb/min, again 3 turns on meter valve, was about the right abrasive flow since productivity decreased above and below this feed rate. It should be noted however, that the low nozzle pressure, 60-80 psi of this test greatly reduced the effectiveness of denser steel abrasive and thus the low productivity rates shown for steel abrasive in Table 1-9.
- Garnet and Glass Blast: Both Garnet and Glass Blast showed optimum performance at a valve setting of 3 turns and 3.5 turns respectively. Opening the metering valve 1/2 turn increased garnet consumption by 7% and Glass Blast consumption by 57% with no change in productivity.

The most significant conclusion from these test results is that excessive abrasive feed not only consumes too much abrasive but also can <u>reduce</u> productivity. In contrast, with the proper metering valve setting, there can be a significant <u>increase in productivity</u> with <u>reduced abrasive consumption</u>.

Conducting the simple metering valve tests as outlined above, can optimize blast cleaning and be a major contributor to reducing a shipyards abrasive consumption.

Abrasive Evaluation Procedure

The test procedure designed to evaluate different abrasives has two objectives; first to determine the cleaning efficiency of an abrasive and secondly to determine the degree of dusting during blast cleaning.

The approach taken to evaluate these two abrasive parameters was as follows:

1. Two 9 ft x 20 ft x 1/2 inch thick steel plates were wheel blast cleaned using S-170 steel shot and coated with 2 mils dry film thickness Ameron 3207 Pre-Construction Primer.
2. The two plates were then connected at the four corners using 2 inch angles 5 ft long and a 10.3 ft diagonal for additional support to form an open-sided box, see Figure 1-4.
3. With this construction the plates, standing on their 20 ft edge, are scribed with chalk into one square foot sections, see Figure 1-4.
4. A 300 lb blast pot, equipped with a Schmidt metering valve and connected to a dedicated compressor, is charged with a pre-weighed amount of abrasive (see Figure 1-3).
5. Use a fixed length of blast hose (for example 50 ft) and maintain 100 psi at the nozzle.
6. With the plate and blast cleaning set-up as described in 3,4 and 5 above, the scribed area is blast cleaned as shown in Figure 1-5 using a measured amount of abrasive and recording the time to complete the blast cleaning.
7. The set-up for each test should be the same to minimize variations due to test procedure.
8. Blast tests should be run between the two plates to evaluate visibility restrictions resulting from dust generation in a confined space, compare Figure 1-6 using steel abrasive with Figure 1-7 using coal slag abrasive. This proved to be a very definitive test for dust generation.
9. This test set-up can also be used to evaluate various types of blast nozzles as well as various nozzle pressure effects.

Tests using the procedure described above were found to be very effective in evaluating various types of abrasive. Figures 1-6, 1-7, 1-8 and 1-9 illustrate some of the visual differences noted between abrasive materials using this procedure. When these results are integrated with the actual productivity as determined by the measured square footage blast cleaned per unit time, it is quite simple to choose the abrasive that will minimize abrasive consumption and maximize productivity.

Figure 1-5: Steel abrasive blast cleaning scribed area to determine abrasive cleaning rate. Note lack of dust.

Figure 1-6: Blast cleaning in a confined space using steel abrasive; note lack of dust and good visibility.

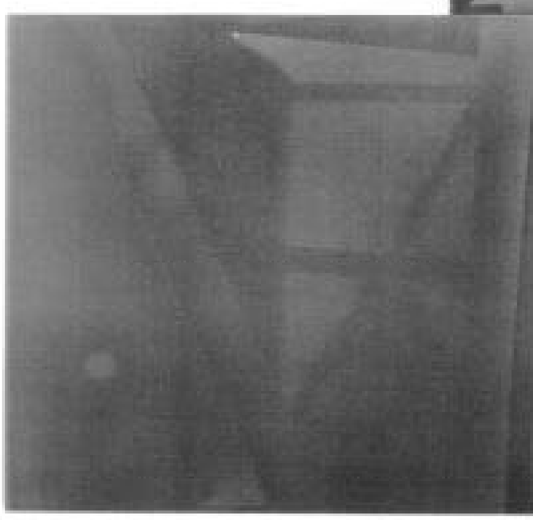


Figure 1-7: Blast cleaning in a confined space using coal slag abrasive; note high dust level and poor visibility.

Figure 1-8

Blast cleaning in a confined space with coal slag; note dust plume.

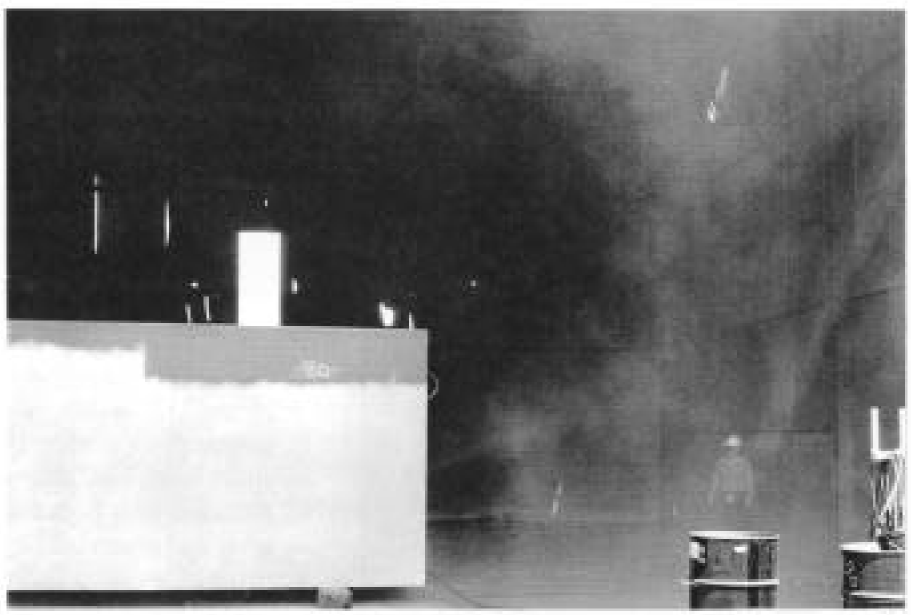


Figure 1-9

Blast cleaning with garnet abrasive in a confined space; note dust plume.

Blast Nozzle Evaluation

Blast nozzle evaluation was accomplished using the same procedure as outlined above for abrasives, only this time the abrasive remained the same and the type of blast nozzle used was changed. Twelve tests included evaluation of three nozzle types. The primary purpose was to demonstrate that the testing technique defined under the **Abrasive Evaluation Procedure** is valid for nozzle evaluation and that in fact different nozzles do produce real differences in abrasive consumption and productivity. The results, shown in Table 1-9 below, clearly show that the type of nozzle does make a difference.

Table 1-9
Nozzle Test Data

Abrasive Media	Steel Abrasive G-50 Grit	Steel Abrasive G-50 Grit	Steel Abrasive G-80 Grit	Steel Abrasive G-80 Grit
Type Nozzle	#8 Double Venturi	#8 Bazooka	#8 Double Venturi	#8 Bazooka
PSI at Nozzle	155	155	155	155
Production (ft^2/hr)	257	527	261	535
Abrasive (lb/hr)	2779	3460	1565	1948
Abrasive (lb/ft^2)	10.8	6.6	6.0	3.6

From the data presented in Table 1-9 it is evident that the Bazooka nozzle out-performed the venturi nozzle both in terms of productivity and in terms of pounds of abrasive consumed per square foot blast cleaned. In each case the amount of abrasive per square foot was reduce by 40% when using a bazooka nozzle compared to a double venturi nozzle. Proper nozzle selection for blast cleaning can therefore, significantly reduce the amount of abrasive used in blast cleaning.

Nozzle Pressure

As part of the study of different nozzles a number of tests using the protocol defined under **Abrasive Evaluation Procedure** were run to confirm the importance of nozzle pressure for improved productivity. What was significant from these test was that not only did productivity increase substantially but also the amount of abrasive consumed per square foot blast cleaned dropped. Table 1-10, Nozzle Pressure Test Data, illustrates the major productivity improvements.

Table 1-10
Nozzle Pressure Test Data

#8 Bazooka Nozzle

Nozzle Pressure, psi	75	155	155
Abrasive Media	G-50 Steel Grit	G-50 Steel Grit	G-80 Steel Grit
Production, ft^2/hr	175	527	535
Abrasive, lb/hr	1385	3460	1948
Abrasive, lb/ft^2	5	6.6	3.6

#8 Double Venturi

Nozzle Pressure, psi	79	155	155
Abrasive Media	G-50 Steel Grit	G-50 Steel Grit	G-80 Steel Grit
Production, ft^2/hr	112	257	261
Abrasive, lb/hr	1260	2779	1565
Abrasive, lb/ft^2	11.3	10.8	6.0

The data, as reported in Table 1-10, shows that two different nozzles were tried; first using yard air and then using a dedicated compressor which gave a nozzle pressure of 155 psi. Also, the tests were run using steel abrasives because steel allows the use of finer abrasive particles that will not disintegrate at these higher nozzle pressures.

When comparing the results at 75 to 79 psi yard air nozzle pressures with 155 psi nozzle pressures, it is evident that the higher nozzle pressures are much more productive, doing 2 to 3 times the amount of work compared to the lower nozzle pressures. What is more important regarding this project is that the amount of abrasive used per square foot Table 1-10, shows a reduction in abrasive consumption of 30-45% when combining high nozzle pressure with fine, G-80 steel grit.

Summary Process Control Standards and Operating Procedures to reduce Abrasive Consumption

The protocol for setting metering valves, evaluating abrasives, nozzles and nozzle pressure have been described, examples presented and an evaluation test form provided as Attachment III. The savings in abrasive consumption and productivity can be substantial when using the protocols described in this Task to optimize a shipyards blast cleaning operation.

ATTACHMENT III

BLAST CLEANING EVALUATION FORM

Location: ____________________ Date: _______________
Test Performed By: ___________________
Type Abrasive Used: __________________

Test Conditions:

Test Panel Size, square ft	________________________________
Test Panel Substrate	________________________________
Surface Condition	________________________________
Coating Type	________________________________
Coating Thickness, mils	________________________________
Nozzle Size, Original, inches	________________________________
Nozzle Size, Gauged, inches	________________________________
Abrasive Media Size, mesh	________________________________
Air Pressure @ Source, psi	________________________________
Air Pressure @ Nozzle, psi	________________________________
Compressor Size, cfm	________________________________
Moisture Control Equipment	________________________________
Hose Diameter, inches	________________________________
Hose Length, feet	________________________________
Whip Hose Diameter, inches	________________________________
Whip Hose Length, feet	________________________________
Type/Size Blast Pot	________________________________
Type Abrasive Metering	________________________________
Abrasive Metering Setting	________________________________

Test Results:

Total Square Feet Blast Cleaned	__________________________
Total Time Of Test	__________________________
Total Pounds Of Abrasive Used	__________________________
Cleaning Rate, ft^2 per minute	__________________________
ft^2 per hour	__________________________
Abrasive Application Rate, lb./ft^2	__________________________
Abrasive disposal Rate, lb./ft^2	__________________________
Level Of Cleanliness, SSPC	__________________________
Profile, PRESS-O-FILM	__________________________

Part 1 Task 4: Preparation of Written Recommendations For Part 2

The approaches taken to accomplish Part 1 of the project are restated below:

- Task 1 gathered data and presented areas requiring further study to achieve process improvement.
- Task 2 took the areas requiring further study from Task 1, ran the experiments, collected the data and drew conclusions.
- Task 3 took the conclusions from Task 2 and established process control standards and operating procedures to achieve the project goal of reducing abrasive consumption in shipyards.

The purpose of Task 4 is to select ideas generated during the process improvement stage of this study and focus on those ideas that have a high potential for reducing abrasive consumption. The ideas selected deal primarily with changes in equipment design and equipment utilization. The discussion of, and recommendations for these equipment changes will be covered under Part 2 Tasks 1-5. A summary of the ideas discussed under Part 2 are listed below:

- Task 1; vacuum-blast as a specialized tool
- Task 2; quick disconnects for metering valves
- Task 3; flexible, large diameter whip hose
- Task 4; nozzle selection
- Task 5; specialized containment equipment

The final task, Task 6 is an outline for a blaster training program. The training outline incorporates most of the findings from this study and also emphasizes the need to look at alternatives and new approaches to blast cleaning. The Shipyard Survey showed that although all the yards have some form of training, these programs are far from complete or up-to-date. A comprehensive training program is needed.

Part 2: Equipment Improvements that Control and Reduce Abrasive Consumption

Part 2 of this study deals primarily with equipment improvements that have proven to control or reduce the use of abrasives. A number of these recommended changes developed as a result of the Process Improvements portion of this study. Other equipment improvement ideas were developed out of necessity.

One of the major hurdles in trying to achieve improvements in the area of blast cleaning is the reticence to change. How can these changes be made user friendly and acceptable to management, supervisors and workers. One of the best ways is to get all three involved in the design, testing and evaluation of the equipment. With involvement comes commitment and a desire to achieve success. Another way to promote change is to create an atmosphere that is willing to take suggestions regardless of the source and give them consideration. Many of the ideas presented in Part 2 are the result of worker-suggested ideas.

Following on with the idea of worker involvement, the final section of this study is an outline for an abrasive blaster training program. In order to implement any changes in a blasters work habits he must understand the importance of these changes to his job. This can best be accomplished through proper training and therefore a training program needs to be established. The training outline forming a part of this study provides a proposed format for a future full-scale training program.

Part 2 Task 1: Vacuum-blast as a Specialized Tool

The contamination of surrounding areas with spent abrasives is a perennial problem during blast operations. The resultant clean-up costs can be many times the cost of blasting because of contamination of adjacent areas and equipment. Screens and tarpaulins are only partially effective, with dust and abrasive debris still escaping from these enclosed areas. And, there is always the labor intensive job of abrasive clean-up when open blasting.

The vacuum-blasting concept offers one of the best methods to minimize dust contamination and costly clean-up from blast cleaning. Unfortunately, under most production operations, vacuum-blasting is too slow and requires too many specialized tools to be used on a large scale. But, just because vacuum-blasting is not practical on a large scale does not mean it is not practical on a small scale. This Section will present the results from four Sub Tasks showing how vacuum-blast can be used effectively and economically.

Sub Task 1: Evaluation of a Portable Vacuum-blast Unit with Abrasive Recycling.

Past practice has been to completely reblast and reapply the prime coat to the reblasted units and subassemblies. An alternate approach was tried using a portable Schmidt vacuum-blast unit with a recycling feature. The approach will be to blast weld and burn areas only on units and subassemblies using a vacuum-blast unit as shown in Figure 2-1. After vacuum-blasting the prime coat will be reapplied only in the blasted areas. In this way the primer is completely restored and the subassemblies are ready for the final coating system. There will be no need for complete reblasting, costly clean-up and costly total repriming of the unit.

The objectives of Task 1 are threefold.

1. Evaluate the effectiveness of the vacuum-blast system in containing abrasive and dust.
2. Determine the effectiveness in vacuum-blast surface preparation of weld areas for priming.
3. Compare the cost of vacuum-blasting and priming weld and damaged areas with the cost of complete unit reblasting and repriming.

Figure 2-1
The vacuum-blast head assembly and
weld areas blast cleaned with the vacuum-blast unit.

Technical Approach:
A portable Schmidt vacuum-blast system with recycling was rented and used to blast weld areas after unit fabrication. Unit 503, a medium sized, 58 ton, Sealift Ship unit was used for the study and consisted of four subassemblies with the following configurations: Fabricated Ts, deck plating with stiffeners, transverse bulkheads, a stair tower with stiffeners and a platform. The test parameters were as follows:

Test Section ID:	Unit 503.
Location:	“T” Beam Shop
Conditions:	Pre-construction primer (pcp) breakdown & weld damage.
Substrate:	A36 mild steel with pcp coating.
Surface Condition:	Failed pcp in weld and abraded areas.
Coating Type:	Water based epoxy, Ameron 3207.
Nozzle Size:	#6.
Blast Media:	Dupont StarBlast
Pressure at Air Source:	100 psi.
Pressure at Nozzle:	80 psi.
Compressor Size:	Yard compressed air distribution system.
Moisture Control Eqmt:	Moisture trap.
Blast Hose Diameter:	1 1/4 inch ID.
Blast Hose Length:	100 ft.
Whip Hose Length:	No whip hose used.
Blast Pot Type & Size:	Schmidt Vacuum-blast unit (see Figure 2-2).
Type of Metering Valve:	Schmidt MicroValve.
Metering Valve Setting:	2 1/2 turns.
Profile:	1.2-1.5 mils.
Degree of Cleanliness:	SP 10, near white.

All weld and burn areas were vacuum blasted and a one mil coating of Ameron 180 primer applied immediately following blast cleaning. The one mil prime coat permitted weld inspection prior to application of the final coating system.

Figure 2-2
Schmidt Manufacturing vacuum-blast unit
(Courtesy Schmidt Manufacturing)

Outcome:
The total man-hours used for vacuum-blasting, priming, final painting and clean-up were 130.5 and this compared to 260 man-hours required to fully blast and paint the unit in the paint and blast room after assembly. Clean-up after vacuum-blasting consisted only of welding debris because all spent abrasive was recovered by the vacuum-blast unit during blasting. Figure 2-2 shows the vacuum-blast unit used for the study.

Conclusions:
The major savings shown by the vacuum-blast study are man-hours and reduced abrasive usage. In the most common practice for this type of job is to blast clean the entire surface of the subassemblies requiring 3-5 lb of abrasive per square foot which then must then be picked up. Using vacuum-blasting, only the weld areas were blast cleaned reducing the total area blasted by more than 90% and the time required for abrasive clean-up by 99%. In both cases the abrasive was recycled, thus minimizing abrasive consumption. Also, the reduced use of abrasive when using the vacuum-blast system requires less total abrasive for additional major savings in abrasive consumption.

Sub Task 2: Vacuum-blast Without Recycling.
One of the drawbacks of a vacuum-blast unit using recycling is that the abrasive capacity is limited and shut down of the vacuum-blast unit is required to empty out the dust and fines. This limitation led the yard to try vacuum-blasting without recycling the abrasive. The spent abrasive was vacuumed with the vacuum-blast unit and simply allowed to collect in a large waste hopper designed for the job and shown in Figure 2-3. The use of this hopper allows the blaster to blast an entire shift without discharging used grit.

Because there is no recycling there is a net increase in abrasive consumption. However, vacuum-blasting still consumes less overall grit because only the weld areas or selected areas are being blast cleaned, instead of the entire surface.

The essentials of the system are as follows:

- A standard vacuum-blast nozzle fitted with a Schmidt 445 cfm eductor vacuum.
- Vacuum line fitted with a 3 inch vacuum hose to minimize line loss for distances of 100 to 200 feet.

- For distances less than 100 feet 2 inch hose can be used.
- Blast nozzle supplied with 100 psi blast pressure.
- Eductor should be fitted with a muffler to minimize noise.

The system, as described above, is used successfully on units and on the building ways after unit erection. Its use exceeded expectations production-wise and allowed work in adjoining areas to continue uninterrupted. Clean-up associated with blast operations was virtually eliminated. The only down side of this approach is that the vacuum-blast hose is very cumbersome and does not permit easy access to confined spaces. It should also be recognized that vacuum-blasting is only used where selective blasting such as weld seams or burn areas is required. Vacuum-blasting is not recommended for large area blasting.

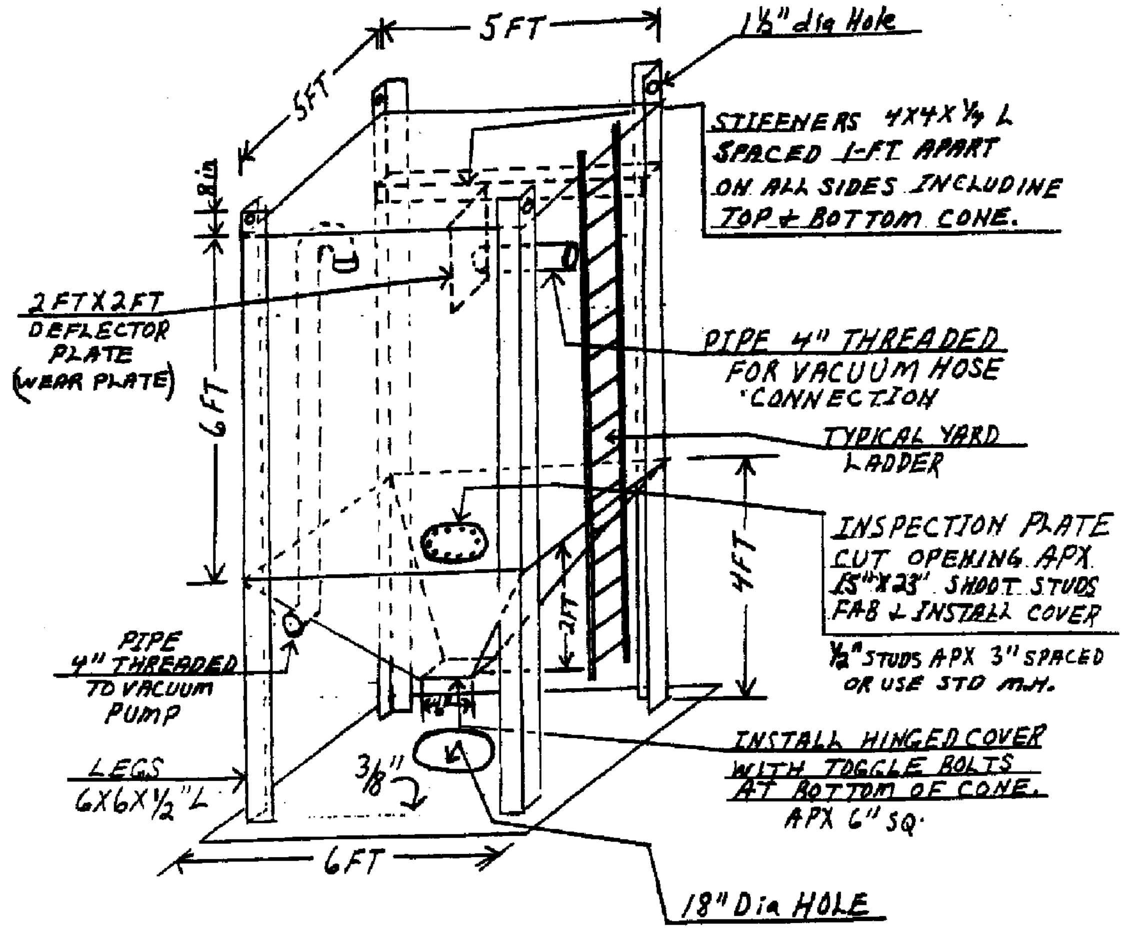


Figure 2-3
Large waste hopper designed for the vacuum-blast unit.

Part 2 Task 2: Use of Metering Valve Quick Disconnects
Metering valves provide one of the best opportunities to reduce abrasive consumption. However, just like any metering arrangement they are subject to plugging which requires tearing down the valve and cleaning out the obstruction. This generally requires shutting down the system, getting out pipe wrenches and opening up the line to remove the plugged valve.

Avondale has experimented with Cam Lock quick disconnect fittings for the metering valves and has saved many man-hours in down-time. Figure 2-3 shows the components of the system and Figure 2-4 shows the system in use. For safety it is recommended that the lock levers be wired in the lock position to prevent premature release after closing the fittings. The wiring of the locking levers is visible in Figure 2-4.

Briefly, the system works as follows:

- When a metering valve appears to be plugged turn off air pressure on that line and release pressure on the valve.
- Close the ball valve between blast pot, which is still under pressure, and the metering valve (this ball valve controls the abrasive flow to the metering valve).
- Release the cam locks on either side of the plugged valve.
- Remove the plugged valve and replace immediately with a working metering valve.

The entire exchange takes place within minutes and the blaster is back on the job with minimum lost time. A job that took several hours and required two or more men can now be accomplished in minutes. There is less abrasive waste because only the valve is removed not large quantities of grit from the blast pot and piping.

Literature on the cam lock connectors is provided in the appendix section.

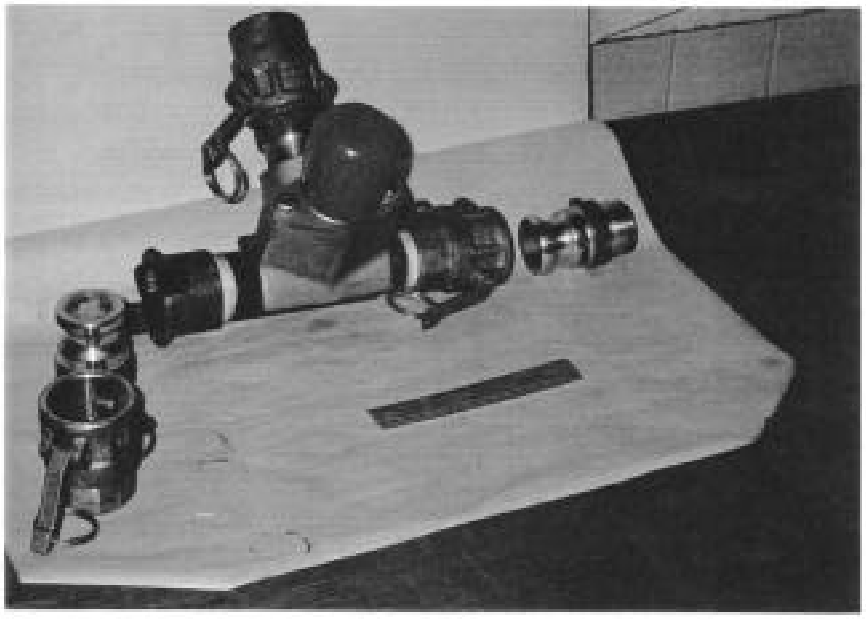


Figure 2-3
Cam Lock fittings on metering valves showing details of system.
(six inch ruler is in foreground for scale)

Figure 2-4
Typical Cam Lock installation on large blast pot.
Note how cams are wired for safety to prevent accidental opening.

Part 2 Task 3: Use of Flexible, Large Diameter Whip Hose.
Blasters historically prefer to use whip hoses on the end of the blast hose because the whips are lighter, less cumbersome and easier to use in confined or tight areas.

Whip hoses are easier to handle because they are half the diameter of blast hose. Unfortunately, this also results in a reduction of the inside hose diameter as well. For example, going from a 1 1/2 inch inside diameter (ID) blast hose down to a 3/4 inch ID whip hose is not just a 50% reduction in hose diameter. This change produces a 75% reduction in hose cross sectional area and a commensurate 75% loss in air volume to the nozzle. This reduction in air volume manifests itself in lower nozzle pressures and therefore lower productivity and increased abrasive consumption.

Avondale experimented with a larger diameter whip hose in an attempt to overcome some of the lost productivity resulting from the use of whip hoses and still give the blaster the ease of handling and flexibility he requires. Extensive use of large diameter, 1 inch ID whip hose has proved to be beneficial. However, the down side is, at 1 inch ID, this is still a 56% reduction in cross sectional area and therefore will result in a substantial reduction in productivity compared to conventional 1 1/2 ID blast hose.

For the last 6 months Avondale has been experimenting with a new 1 1/4 inch ID High-Flex whip hose and has realized a significant, 10-15% increase in productivity. The new Hi-Flex hose is constructed with two plies of polyester and uses only virgin rubber to maintain flexibility. Typical configurations are shown in Figure 2-5. The manufacturer of Hi-Flex recommends using a wide entry nozzle with the hose to minimize turbulence at the hose-nozzle interface and further increase blasting efficiency.

Blasters like the ease-of-handling that whip hoses provide but, the loss in productivity that comes with their use can be costly to a shipyard. The use of Hi-Flex, large diameter whip hose may be the answer. The approximately 30% loss in productivity resulting from reduced blast hose ID when going from 1 1/2 blast hose to a 1 1/4 inch Hi-Flex whip hose can be overcome in part by making the blaster more mobile and overall blasting less fatiguing. The bottom line is, if the blaster is more productive, then abrasive consumption is reduced.

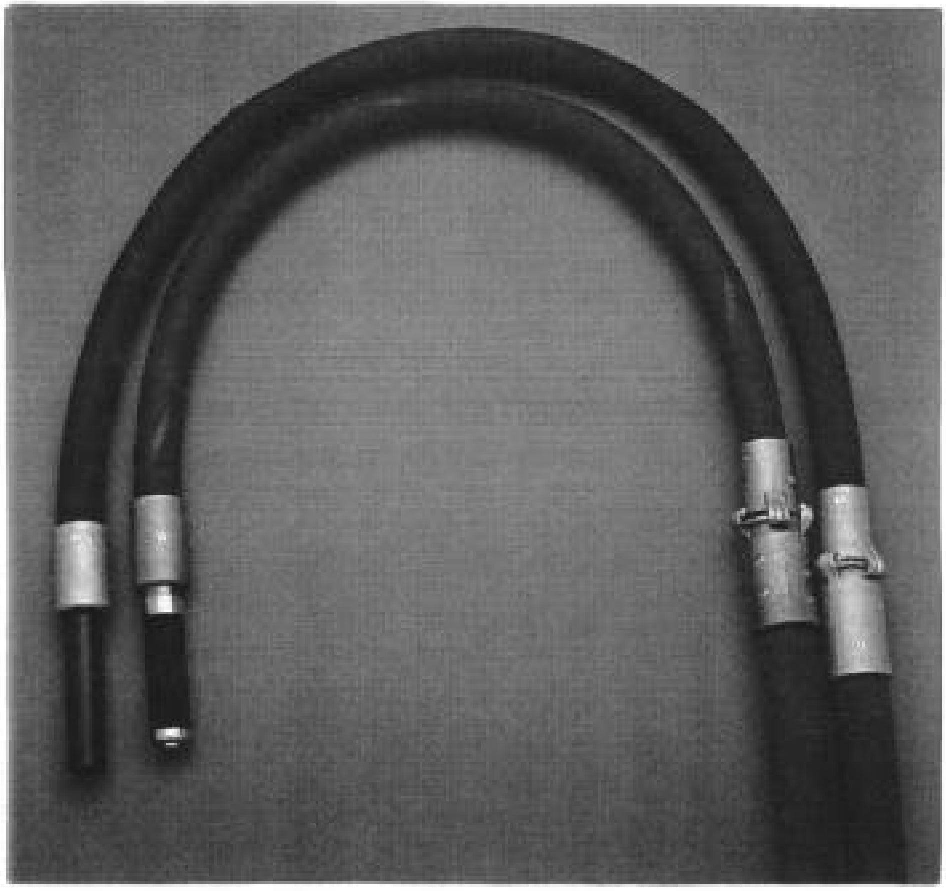


Figure 2-5
Hi-Flex blast hose configurations showing 1¼ inch ID Hi-Flex hose connected to 1¼ inch ID blast hose.
(Courtesy MARCO)

Park 2 Task 4: The Importance of Blast Nozzle Selection and Inspection

The key to getting a job done efficiently is using the right tool for the job. This is as true for blast cleaning as it is for any job. This task will discuss the various blast nozzles available and provide an outline of nozzle types and applications, matching the right tool for the job.

Figure 2-6 illustrates the variety of nozzles available along with a generalized nozzle bore configuration. There are two basic nozzles bore types, straight bore, Design #1 in Figure 2-6 and venturi bore, Designs #2-5 in Figure 2-6. A generalized description, application and advantages of these two basic types of nozzles follows:

- Straight bore nozzles give a tight blast pattern and are best suited for blasting small areas such as handrails, spot blasting, weld seams and generally small areas.
- Venturi bore nozzles create a wide blast pattern and are best suited for large, open blasting. Venturi nozzles increase nozzle velocity by as much as 100% over straight bore nozzles making the venturi nozzle 35% more productive and consuming 40% less abrasive.

Because of the variety of venturi nozzles, the features of each of the design types shown in Figure 2-6 will be described along with specific applications for that design type.

- Design # 2 has a long entry throat to reduce turbulence and a standard exit end. This nozzle is best suited for low to medium nozzle pressures.
- Design #3 has a short entry throat and a standard exit end. Again, this nozzle is best suited for low to medium pressure nozzle blasting.
- Design #4 is a double venturi and can be thought of as two nozzles in series with a gap and holes in between to allow atmospheric air into the second nozzle portion. The nozzle is longer and exit end of the nozzle is wider than both Design #2 and #3 nozzles. Design #4 nozzle is best suited for higher, greater than 100 psi, nozzle blasting.
- Design #5, the Bazooka nozzle, has a long entry, wide throat, long diverging exit and is 20-30% longer than conventional nozzles. The nozzle especially designed for high pressure and will yield a 60% larger blast pattern with lower abrasive consumption rates.

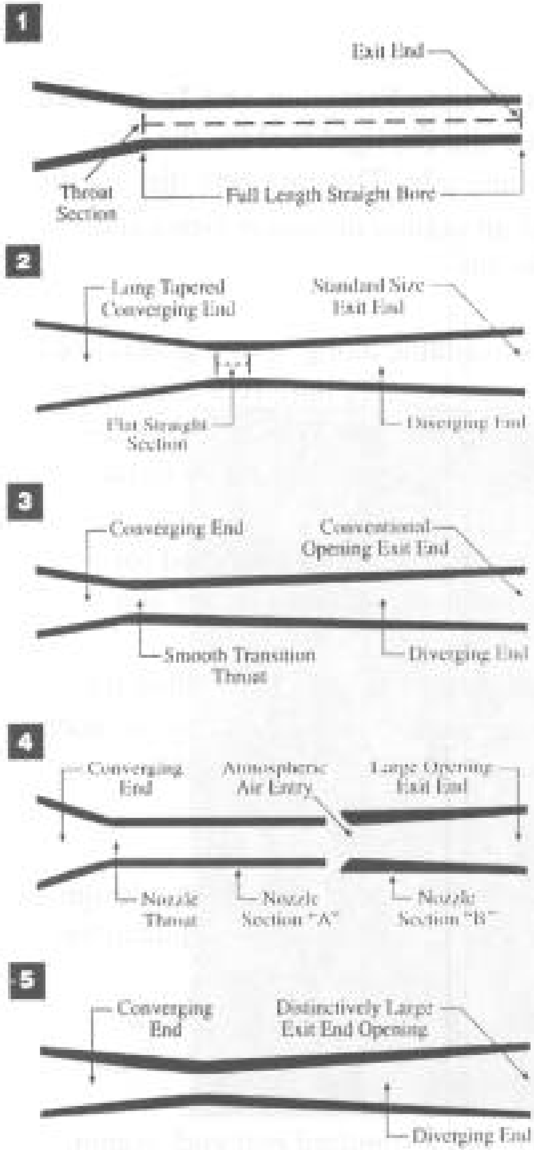


Figure 2-6
The variety of nozzle bore configurations available.
1. Straight bore
2. Conventional design long venturi
3. Laminar flow design long venturi
4. Double venturi
5. High pressure venturi
(Courtesy BORIDE PRODUCTS)

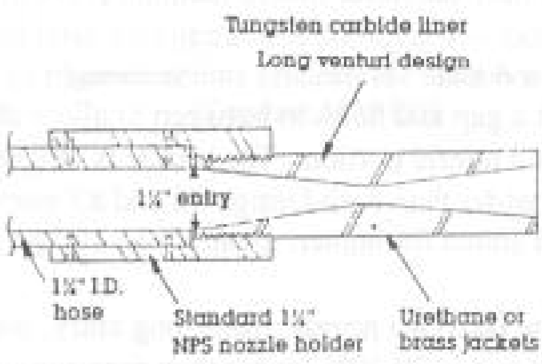


Figure 2-7
Entry throat of the nozzle should match the blast hose diameter.
(Courtesy MARCO)

In addition to the configuration of the nozzle, some other points to consider when choosing a blast nozzle are:

- Air Supply: Does the compressor provide sufficient air to support the nozzle? A general rule covering this is the air supply should supply 50% more cfm than the nozzle will need to develop the required working blast pressure, be it 100 to 140 psi.
- Nozzle Entry Throat: The nozzle entry throat, see Figure 2-7, should match the blast hose ID to minimize turbulence and maximize efficiency of energy transfer from air to abrasive.
- Bore Size: Select the bore size that will give the desired blast pressure at the available air flow and generate the degree of productivity required. Table 2-1 illustrates some typical requirements; actual values will vary with the type (bazooka, venturi, straight bore) nozzle used.
- Nozzle Material: Boron carbide and silicon carbide are both very abrasion resistant, but they are not as tough and flexible as tungsten carbide. How ever tungsten carbide nozzles are not as wear resistant as boron and silicon carbide nozzles. For rough applications, tungsten carbide is probably the better choice. Boron carbide is the most wear resistant nozzle material, out-wearing tungsten carbide five to ten times and silicon carbide two to three times.
- Abrasive Type: For high wear abrasives such as aluminum oxide, boron carbide is the recommended nozzle material. For mineral and coal slags, silicon or tungsten carbide nozzles are a good choice.

Nozzle Wear: One of the old concepts is; as a nozzle wears, it gets better. This may have been true with the old, straight bore nozzles because as the straight bore gradually wore, it wore into a rough venturi configuration. However, for the modern venturi nozzles this is not the case. As the diverging end of the nozzle wears, the abrasive flares out more and more losing velocity and reducing productivity. Regular use of a nozzle diameter gauge, described in Part 1 Task 2 and shown in Figure 1-1, is the best method to determine nozzle condition. If there is more than 10% increase in nozzle diameter it is time to change nozzles. Visual inspection is also recommended. Any evidence of rippling or “orange peel” on the carbide liner indicates excessive wear and that also indicates it is time to replace the nozzle.

To Summarize:

- Short nozzles give wide blast patterns at close range while longer nozzles give larger, denser blast patterns at greater distances.
- Longer venturi nozzles clean faster with less abrasive consumption than shorter or conventional straight bore nozzles.
- Straight bore nozzles are best suited for close, limited blasting such as spot blast, hand rails, weld seams, etc.
- Venturi nozzles are best suited for large area, open blasting.
- When selecting a nozzle be sure to consider and look for the following:

Air supply	Type of abrasive
Bore size	Nozzle material
Check for nozzle wear.	Nozzle entry throat

Table 2-1
Air, Horsepower & Abrasive Requirements
For Given Nozzle Diameters & Nozzle Pressures
(Courtesy BORIDE PRODUCTS)

Nozzle Orifice (inch)	Blast Cleaning Component	Nozzle Pressure (psi)							
		50	60	70	80	90	100	125	140
3/8	Air (cfm)	110	125	145	160	175	200	275	315
	Horsepower	25	29	32	35	40	45	57	65
	Abrasive (lb/hr)	675	775	875	975	1060	1100	1350	1840
7/16	Air (cfm)	150	170	200	215	240	255	315	405
	Horsepower	35	40	45	50	55	60	70	90
	Abrasive (lb/hr)	900	1000	1200	1300	1400	1550	1800	2540
1/2	Air (cfm)	200	225	250	275	300	340	430	540
	Horsepower	45	50	55	63	70	75	95	120
	Abrasive (lb/hr)	1200	1350	1500	1700	1850	2050	2525	3240

Part 2 Task 5: Specialized Vacuum-blast Containments for Post Construction On-Board Blast Cleaning

After ship construction and prior to delivery there are many areas requiring final spot blast and painting. Open blasting of these areas causes major problems with other crafts and could seriously damage neighboring coating, machinery and other ship-board equipment. To overcome these difficulties Avondale developed some mini, portable containments for use in blast cleaning two specific areas; deck tie-down fittings and small area paint damage.

Sub Task 1: Deck Tie-Down Blaster

The unit for blasting tie-downs is shown in detail in Figure 2-8 and in actual operation in Figure 2-9. Briefly, the unit consists of a 12 inch diameter inverted aluminum funnel fitted with a pipe capable of accommodating a 2 1/2 inch pipe sleeve for the blast nozzle. Coming off the side of the pipe is a 3 inch diameter pipe for connecting the vacuum hose.

During operation the inverted funnel is placed over the tie-down and blasting commences along with the vacuum recovery. Initially a 2 inch vacuum line was used but there was insufficient vacuum air flow and the vacuum line sanded up. The funnel was modified and fitted with a 3 inch vacuum line and no further problem was experienced. The 3 inch vacuum line provided an additional benefit; it permits operation several hundred feet from the vacuum receiver.

The tie-down blast unit has solved a major clean-up problem associated with conventional open blasting of tie-downs. As shown in Figure 2-9, when using the tie-down blaster system there is no abrasive debris to clean-up and other crafts, including painting and welding, can continue unhampered adjacent to tie-down blasting. In addition, this system require less abrasive and permits the use of recyclable abrasives reducing overall abrasive usage, a primary goal of this project.

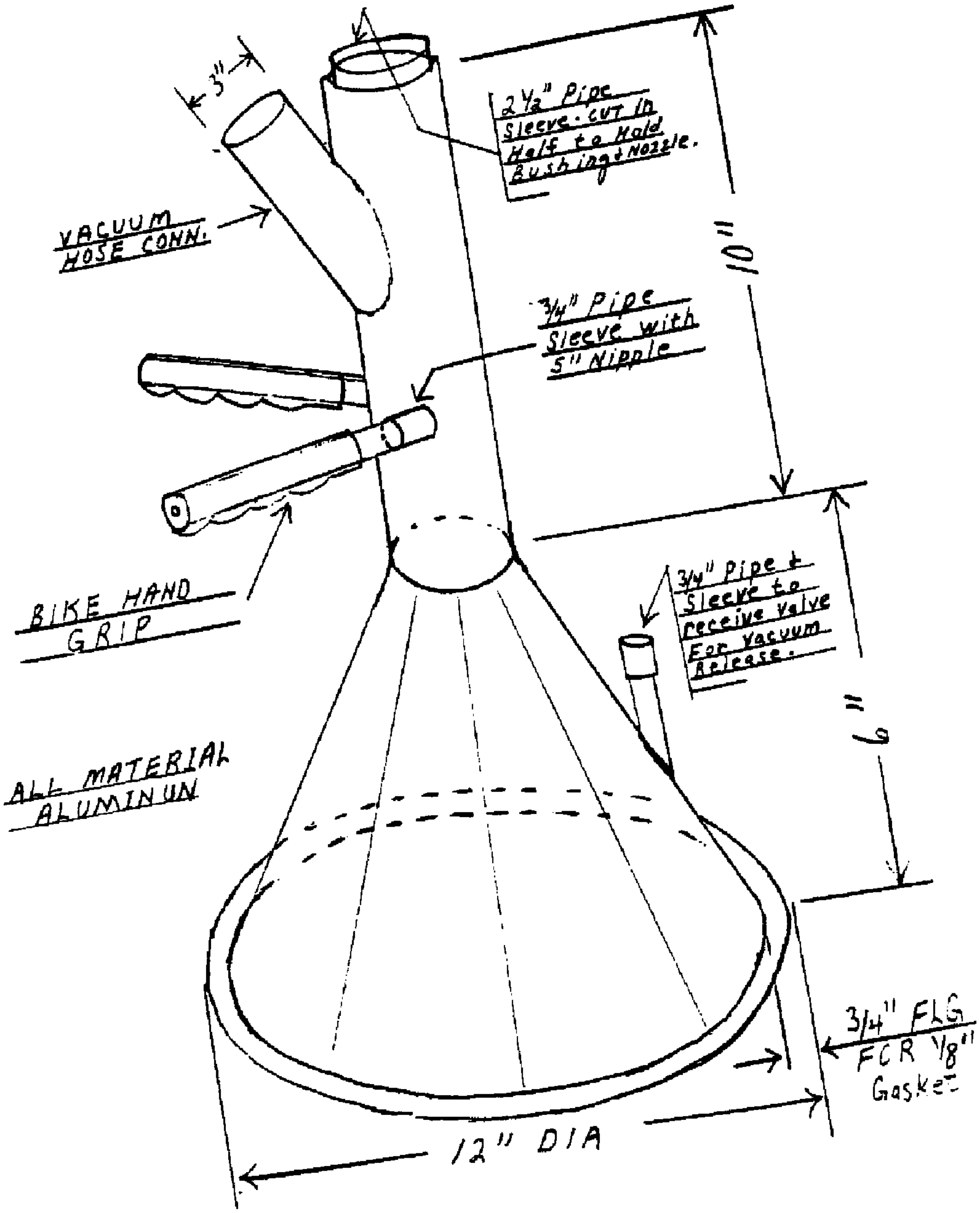


Figure 2-8
Drawing of Deck Tie-Down Blaster containment-vacuum-blast system

Figure 2-9
Tie-Down blaster in operation. There is no abrasive debris evident, other crafts are working adjacent to the blasting

Sub Task 2: Small Area Paint Damage

The unit for blasting a small area of damaged paint is shown in Figure 2-10 and in operation in Figure 2-11. Briefly the unit consists of the following:

- A 16 x 36 x 12 inch box fitted with a blast hose and vacuum line.
- The box is fitted with two long sleeve gloves for manipulating the blast hose.
- The box is fitted with a Plexiglas window for viewing the work area.
- Magnets hold the box in place until the vacuum line is activated.
- The box is constructed of aluminum, making it light weight and portable.

As with the tie-down blaster, the small area paint damage blaster allows other crafts to work adjacent to the unit unhampered. There is no abrasive clean-up
and recyclable abrasives can be used reducing overall abrasive usage. This particular unit was specifically designed for hull blasting as shown in Figure 2-11. However, a similar unit could be used for top-side or interior blasting as well.

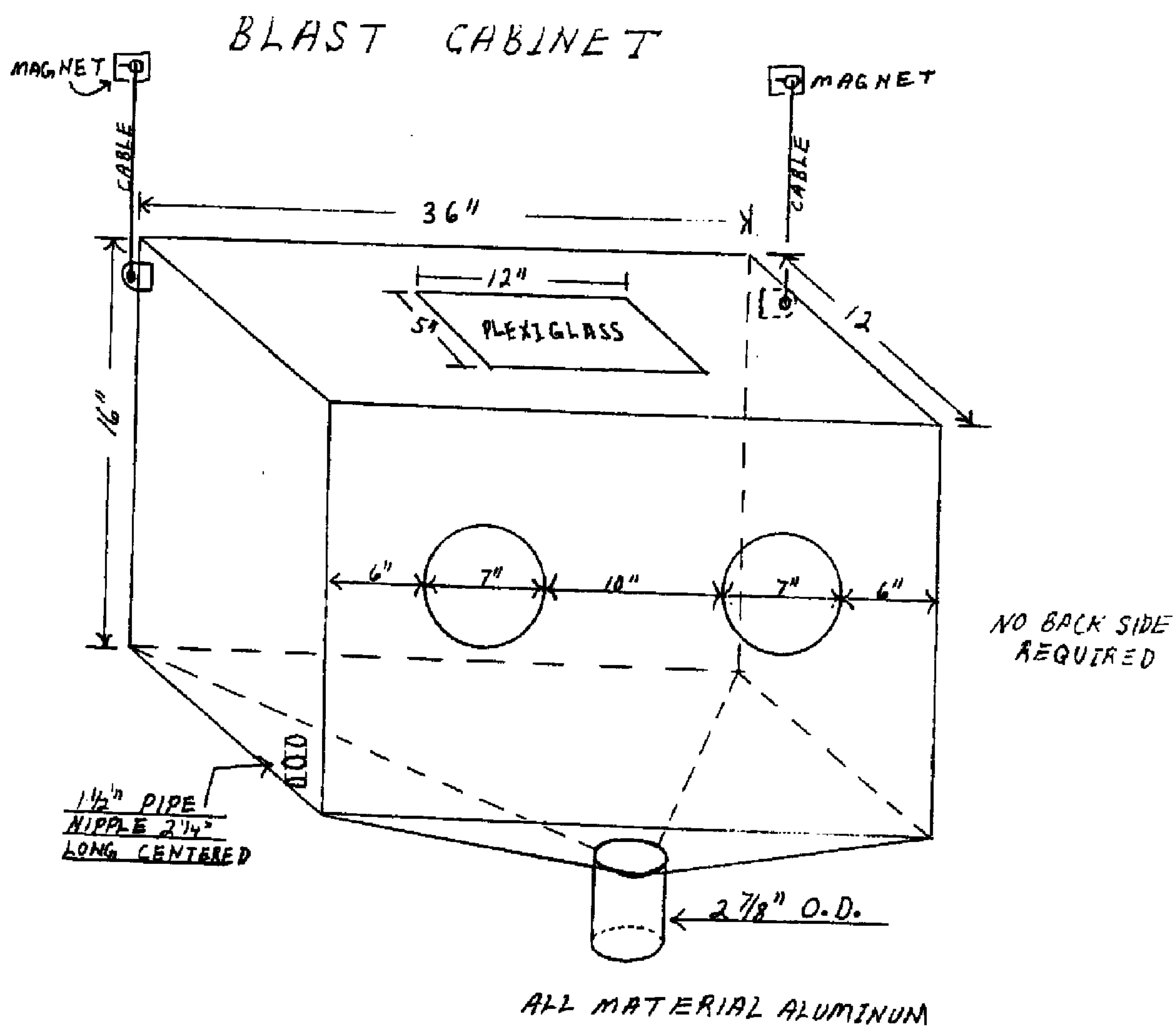


Figure 2-10
Drawing of Small Area Blaster containment-vacuum-blast system

Figure 2-11
Small Area Blaster in use on a vertical surface. Note lack of dust and abrasive escaping from containment.

Part 2 Task 6: Outline For An Abrasive Blasting Training Program

The outline presented here covers the topics that should be included in a training program for blast cleaning. With the advent of new surface preparation technology, emphasis on reduced abrasive usage and need for higher productivity; it is important that abrasive blast cleaning incorporate the best and most current methods to remain competitive. Education and involvement in the innovation process will motivate blasters to do their best work. The proposed training program is the first step.

1. Introduction and Overview
    - Purpose of Program
    - Program Objectives
    - Student Goals
2. Parameters Affecting Blast Cleaning
    - Type of abrasive: Discuss the various types of abrasive available and some typical applications illustrating how different abrasives are used for different applications.
    - Degree of Surface Cleanliness: Discuss the various types of blast cleaning, i.e. brush blast, touch-up, near white, white metal, etc. and how different abrasives and blasting techniques are used for these various degrees of surface cleaning.
    - Abrasive Metering: Review the importance of proper metering of abrasive to the blast nozzle. Explain how the optimum abrasive metering is accomplished and how this can make blast cleaning faster and more efficient.
    - Blast hose length: Review the effect on nozzle pressure with increasing length of blast hose.
    - Blast hose inside diameter (ID): Illustrate how changes in hose diameter affect blast cleaning rate and productivity.
    - Nozzle pressure: Describe how nozzle pressure is measured and why it is important to periodically measure nozzle pressure.
    - Nozzle pressure Vs blast pot pressure: Explain why pressure at the blast pot does not indicate pressure at the nozzle.
    - Nozzle size: Describe how nozzle inside diameter is measured and why it is important not to use nozzles with excessive wear.
    - Nozzle type: Discuss the various types of nozzles available and illustrate applications. Review some of the new technology regarding nozzle designs.

- Profile: Discuss how profile is influenced by type, size and hardness of abrasive and by nozzle pressure.
- Nature of Substrate: Discuss how various type of steel substrate can influence blast cleaning.
- Compressed Air Moisture Control: Discuss the need for air dryers and after coolers to remove moisture from compressed air.

3 Parameters Affecting Abrasive Productivity:

- Nozzle Pressure: Cite examples of how increasing nozzle pressure can double or triple productivity.
- Nozzle Distance from Work: Discuss the effect of being too close or too far from the blast surface.
- Angle of Abrasive Blast: Discuss how angle of abrasive impingement can effect productivity.
- Type of Abrasive: Discuss variations among abrasives such as physical and chemical differences.
- Particle Size: Explain how particle size effects cleaning rate and profile. Explain how particle size interacts with nozzle pressure.
- Hardness of Abrasives: Discuss the effects of abrasive hardness on cleaning and profile. Show that harder is not always better.
- Specific Gravity of Abrasives: Define specific gravity and explain how it influences abrasive cleaning rate.
- Particle Shape of Abrasives: Describe the various particle shapes; round, angular, irregular, etc. and explain how particle shape influences cleaning rate, profile, surface appearance and texture.
- Condition of Surface Being Cleaned: Describe how different surface conditions; i.e. mill scale, rust, paint, etc. require different abrasive types for effective cleaning.

4. Typical Blast Cleaning Scenarios:

   Show how all the blast cleaning parameters discussed interact.

5. Alternate Surface Preparation Methods:
   - Water Blasting with and without abrasive injection.
   - Power Tool Cleaning.
   - Vacuum-blasting.
   - Chemical Cleaning

6. Hands-On Training:
    - Selection of protective wear and breathing apparatus.
    - Safety hazards.
    - Operation of blast pot.
    - Adjusting abrasive metering valves.
    - Nozzle pressure testing.
    - Nozzle wear testing.
    - Nozzle selection and actual blasting.
8. Summary, Review and Key Points.

REFERENCES

1. PROTOTYPE MINERAL ABRASIVE RECLAIMER: SHIPYARD OPERATION, US Department of Transportation, Maritime Administration, March 1987.

2. SURFACE PREPARATION & COATING HANDBOOK NSRP Publication 0412, June 1994.

3. GOOD PAINTING PRACTICE, Steel Structures Painting Council, 2nd ed., 1989.

4. SYSTEMS AND SPECIFICATIONS, Steel Structures Painting Council, 6th ed., 1991.

5. REDESIGNING BLASTING NOZZLES TO IMPROVE PRODUCTIVITY, Journal of Protective Coatings and Linings, October 1996.

Appendix III

LIST OF EQUIPMENT, COMPANIES AND LITERATURE REFERENCED IN THE TEXT

ABRASIVES

GMA Garnet supplied by Barton Mines, Lake George, New York

GlassBlast supplied by Glass Recycling Inc. Marietta, Georgia

METgrain Steel Abrasive supplied by Chesapeake Specialty Products, Baltimore, Maryland

STAN-BLAST Abrasives supplied by STAN-BLAST Abrasives Co., Inc. Harvey, Louisiana

StarBlast Abrasive supplied by DuPont, Stark Florida

NOZZLES

BORIDE Products, Inc. Traverse City, Michigan

MARCO Blast Cleaning Equipment and Accessories, Davenport, Iowa

QUICK DISCONNECTS

EVER-TITE Cam Lock Couplings

HI-FLEX WHIP HOSE

HiFex or SuperFlex Blastmaster blast hose supplied by MARCO Blast Cleaning Equipment and Accessories, Davenport, Iowa

METERING VALVES

MicroValve supplied by Schmidt Manufacturing, Inc. Fresno, Texas

HIGH PRESSURE BLAST EQUIPMENT

High Pressure Blast Pots supplied by Ingersol Rand, Mocksville, North Carolina

ABRASIVE BLAST-RECOVERY-RECYCLING

----- unit supplied by Environmental Containment Systems, Houston, Texas

VACUUM RECOVERY EQUIPMENT

Abrasive Vacuum Units supplied by Ingersol Rand, Mocksville, North Carolina

----- unit supplied by Environmental Containment Systems, Houston, Texas

Abrasive Vacuum Unit supplied by Schmidt Manufacturing, Inc. Fresno, Texas

VACUBLAST EQUIPMENT

Vacublast Unit supplied by Schmidt Manufacturing, Fresno, Texas

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