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ABRASIVE BLASTING SYSTEMS

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Abrasive blasting requires various essential equipment elements for productive cleaning or treating of metal surfaces. The blasting process involves projecting abrasive particles using compressed air as the source of power. Successfully converting compressed air and motionless abrasive particles into an effective cleaning treatment takes a combination of common sense and engineered components. Each element in an abrasive blasting system is a major contributor to the overall performance of the system. If one element is faulty, for whatever reason, the entire system will fail to fulfill its expected level of achievement.

The abrasive blasting process is well known for outside cleaning of bridges, ships, and other steel substrates. It is, however, a highly productive method of cleaning and treating metal surfaces in enclosed systems. Enclosed systems range from manually operated cabinets, where the operator is positioned outside of the blast chamber, to large rooms where one or more operators work inside the enclosures. Within this range, enclosed systems offer countless options of standard and custom-designed automated features tailored to production and treatment requirements. Whether work is performed inside or outside, manually or automated, blasting productivity is determined by the selection and use of effective components.

APPLICATIONS

A wide range of applications exists for abrasive blasting. Although the most familiar are blasting steel bridges and concrete buildings, there are many other common blasting processes that improve the appearance of parts, remove unwanted flashing and burrs, or add strength to high-stress materials. Three of the more prevalent applications are described below.

Surface Preparation

This application category encompasses the process of preparing surfaces for coating materials. Widely known is blast cleaning of steel to remove old paint, rust, and other contaminants, or, if it is new steel, removing mill scale that has formed on the steel surface during the manufacturing process. The second major function when blasting steel is producing a surface profile. Profile, which is also called "etch" or "roughness," is the texture resulting from impact of abrasive particles on the surface. Coating manufacturers generally specify the type of profile required to ensure that their coating material will perform as designed.

Surface preparation applications are not restricted to steel and masonry. Fiberglass materials are blasted to remove the top layer of glaze (gelcoat) and expose air bubbles. Aluminum, titanium, magnesium, and other sophisticated metals require elimination of corrosive matter and, if they are to be coated, a surface profile. Highly advanced materials, such as composites used in aircraft and aerospace industries, are blasted with the newer, less aggressive, abrasive media. Airplanes, helicopters, car bodies, trucks, and boats are stripped of their deteriorating paint by blasting with plastic, wheat starch, and agricultural media at low air pressures.

The list of blast cleaning possibilities is endless. With the vast available range of abrasives and media, and various types of process equipment, there is the potential that the surface preparation on most materials can be accomplished by abrasive blasting.

Surface Finishing

Surface finishing differs from surface preparation in that the desired result of abrasive blasting is to improve the appearance and utilization of a product, rather than condition it for coating. Typical surface finishing processes are deflashing and deburring of mold-formed parts, removal of production contaminants, and enhancement of visual features.

Primary users of abrasive blasting are metal foundries where parts are produced by sand casting, permanent mold casting, and die casting. Cast parts almost always have small burrs, which must be removed for functional and aesthetic purposes. An added benefit of blasting cast parts is the ability to reveal minute cracks and defects that are not readily visible. This advantage is especially important to aircraft repair facilities that recondition airplane wheels.

Softer molded materials, such as rubber and plastics, usually emerge from molds with flashings caused by tooling separation. In many cases, flashings can be quickly trimmed off by abrasive blasting, leaving a smooth, uniform finish.

There is an enormous market for abrasive blasting in industries that use heat treating as a hardening process. Heat treating requires tremendously high temperatures, which normally create discoloration of parts. Blast cleaning these parts with various types of blast media easily removes discoloration and any heat-treat scale, which also may have formed.

Another common purpose of abrasive blasting is to improve the appearance of a product. Several types of abrasive and media are used to remove stains, manufacturing compound residue, corrosion, and tool marks. Some media can blend visual surface variations into an overall uniform appearance. This is especially true on parts with scratches and cuts caused by tooling fixtures.

High operating temperatures and hot lubricants cause buildup of carbon and burnt oil on many automotive parts. Electric motors become clogged with overheated insulation and melted motor stator lamination. In most cases, retaining original dimensions of a part is critical. Use of abrasive and media that do not affect tolerances, such as plastic media, glass beads, and agricultural abrasive, allows the integrity of the part to be maintained while removing unwanted contaminants and providing an acceptable cosmetic effect.

Surface Compression

Compressing a surface by abrasive blasting is a specialized field that has become essential to the life of high-stress components. The compressing technique by abrasive blasting is called "shot peening." Increased fatigue strength of metal surfaces is achieved by bombarding the surface with a high-velocity stream of preselected round balls. Steel shot, ceramic shot, and glass beads are prominent media used in the shot peening process. Peening gives the effect of stretching and compressing the surface, thereby reducing operational stress. As a result, a shot-peened part is more durable than its original form.

Shot peening is a rather precise science, as underpeening and overpeening may cause early failure of a given part. Exacting specifications are written and must be followed in most applications. Two major users of shot peening are the automotive and aircraft industries. Gear manufacturers use peening to eliminate burrs and sharp edges, as well as to add strength to gear teeth. Spring manufacturers use shot peening extensively to combat stress tension throughout their products.

Another popular use of shot peening is on metal castings and forgings. In these cases, there are multiple benefits of the peening process. Shot peening provides part cleaning, elimination of porosity, exposure of defects, and improvement in appearance. Many threaded parts incorporate the peening process to remove sharp edges while increasing thread holding power.

STEEL SURFACE PREPARATION SPECIFICATIONS

There are two highly important requirements in preparing steel surfaces for painting; one is *surface profile* and the other is *degrees of cleanliness.* Both are critical to the performance of any coating system, especially with the advanced, long-life formulations used in coatings today.

Coating manufacturers have long recognized the necessity of proper surface preparation if their coatings are to succeed as they have claimed. Improperly cleaned steel surfaces will cause costly premature failure of the coating; consequently, coating manufacturers specify how the surface is to be cleaned and textured prior to applying their products. Failure to follow specifications results in denial of coating performance guarantee.

Surface Profile

Considerable research has been conducted by coating manufacturers and professional organizations on surface profiles required for various paint systems under a wide range of environmental conditions. Studies have found that certain types of coatings require specific profiles to ensure adhesion and complete protection of the substrate. Profiles provide a mechanical method of positive, uniform bonding of the coating, allowing the coating to last as long as stated by the manufacturers.

Profile, which is sometimes called "etch" or "roughness," is produced by abrasive particles propelled by compressed air at high velocity from an abrasive blast nozzle against a surface. Abrasive particles cut into the steel to form countless peaks and valleys. The resultant contour provides a surface on which the applied coating can obtain a tight grip. Sophisticated coatings simply will not adhere to flat, smooth surfaces because there is nothing for the coating to grasp

Depth of profile is controlled by the size, type, and hardness of abrasive, and by the pressure, surface distance, and impact angle of the blast nozzle. Different abrasives create different profiles; therefore, selection of the abrasive is extremely important in complying with specifications.

Profiles are measured in mils or microns. A mil is 1/1,000 of an inch. A micron is 1/25 of a mil (i.e., 25 microns equal 1 mil). The most common term used in the United States is mil, which is used to measure paint thickness, as well as surface etch. Typically, specifications state a mil profile height average due to the wide range of abrasive particle sizes within a given abrasive supply. For example, an average profile of 2 mils (50 microns) may actually show a mixture of profiles as small as 1 mil (25 microns) and as large as 3 mils (75 microns). Precise profiles are simply not possible because there is no practical method of producing exact abrasive particle sizes.

Once the abrasive has been selected, it is important to establish strict blasting techniques. Any deviation in nozzle air pressure, nozzle distance from the surface, or angle of abrasive impact will affect profile results. Reduction of air pressure or increased nozzle distance may cause smaller profiles. Severe nozzle angles may produce a skimmed blast pattern, rather than definite peak and valley projections of a profile. For best results, nozzles should be positioned to blast at 80–90° to the surface and at a distance where abrasive speed reaches its optimum acceleration.

There are various types of instruments for measuring profiles. It is essential to utilize a measuring device to check and document profile conformance. Careful monitoring of the profiles will prevent expensive rework (see Fig. 1).

Degrees of Cleanliness

Proper blast cleaning of steel surfaces is an absolute necessity prior to applying coatings. It is no mystery that paint will not last long on a dirty, rusted, or contaminated steel surface. New steel must also be blast cleaned to remove mill scale, as mill scale will loosen in time and cause premature paint failure.

Depending on the coating and type of service to which the steel product is subjected, four grades of cleanliness have been established by professional industrial organizations. The four grades are classified as degrees of cleanliness, which range from 100% removal of all contaminants to a quick blast to remove only loose materials. The four degrees are white metal blast, near white metal blast, commercial blast, and brush-off blast. Several pages of the Steel

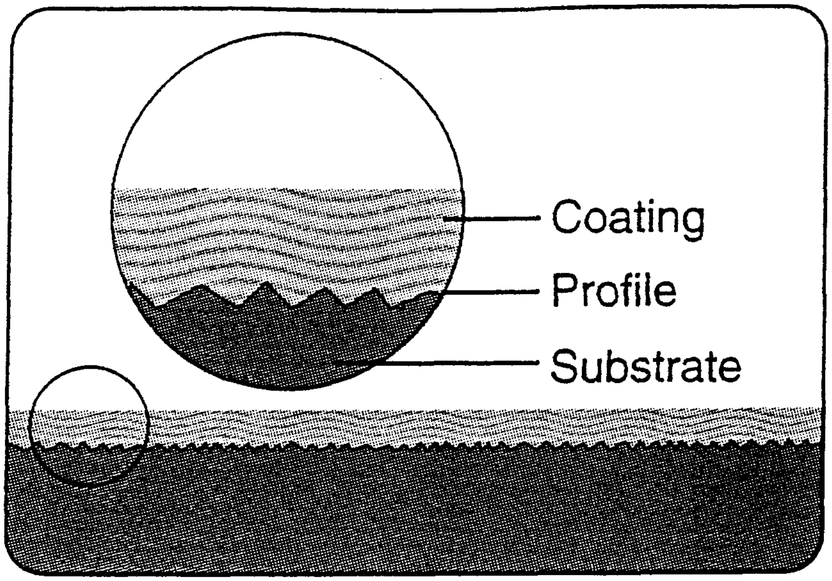

Fig. 1. When surface profiles exceed the maximum specifications, the peaks may protrude through the coating system, causing it to fail.

Structures Painting Council's (SSPC) *Systems and Specifications Manual* are devoted to describing each degree of cleanliness, but a brief definition follows.

White metal blast: Removal of all visible rust, mill scale, paint, and foreign matter. This level of cleanliness is usually required where sophisticated paints, such as zinc-rich coatings, are applied to materials that are located in highly corrosive areas. Typical applications are salt water bridges, chemical plants, and offshore drilling rigs.

Near white metal blast: Blast cleaning until at least 95% of the surface area is free of all visible residue. Very similar to white metal, but allowing for some slight staining on the metal. This degree of cleaning is required for high-performance coatings where the steel is exposed to harsh elements and heavy usage.

Commercial blast: Blast cleaning until at least two-thirds of the surface is free of all visible residue. For most applications where standard coatings are applied, commercial blast is specified. It primarily allows tightly adhering old paint to remain on the surface because of the contention that if the old paint is still good, why remove it.

Brush-off blast: Blast cleaning of all except tightly adhering residues of mill scale, rust, and coatings, exposing numerous evenly distributed flecks of underlying metal. This cleaning method is acceptable for materials that are not subjected to severe environments or where long-term coating life is not expected.

Complementing the written definitions of degrees of cleanliness are several visual comparators produced by professional organizations. The SSPC has produced a set of photographs in a pocket booklet form that shows the cleanliness grades on four types of surface conditions. The four conditions cover steel surfaces with mill scale, mill scale and rust, total rusting, and rust with pitting. The National Association of Corrosion Engineers (NACE) developed a set of encapsulated steel coupons that simulate the four degrees of cleanliness. For reference, the four degrees of cleanliness standards are shown in Table I.

Abrasive blasting should be attempted only by trained and experienced personnel knowledgeable in the standards of surface preparation. Advancements in the quality and longevity of paints developed by coating manufacturers dictate the need for perfection in surface preparation.

BLASTING PRINCIPLES

There are two operating principles of blasting—*suction blast* and *pressure blast*. Suction machines are usually small pieces of equipment primarily designed for light duty work or

Table I. Standards for Cleanliness

Degree of Cleanliness	*SSPC Std.*	*NACE Std.*
White metal blast	SSPC-SP 5	NACE No. 1
Near white metal blast	SSPC-SP 10	NACE No. 2
Commercial blast	SSPC-SP 6	NACE No. 3
Brush-off blast	SSPC-SP 7	NACE No. 4

minor cleaning applications. The most common use of the suction principle is in blast cabinets where work areas are limited and blasting requirements are less aggressive. Pressure blast machines are also used with cabinets for tough cleaning jobs. Pressure blasting is utilized in blast room applications.

Suction (sometimes called "venturi") uses a method of drawing abrasive from a nonpressurized container into a gun chamber and propelling abrasive particles out of a nozzle. Typically, a suction system consists of a blast gun, two hoses—one for air and one for abrasive—and an abrasive container. The blast gun has a nozzle, air jet, gun body, and hose connections (see Fig. 2). By mounting an air jet in line and behind a nozzle, compressed air

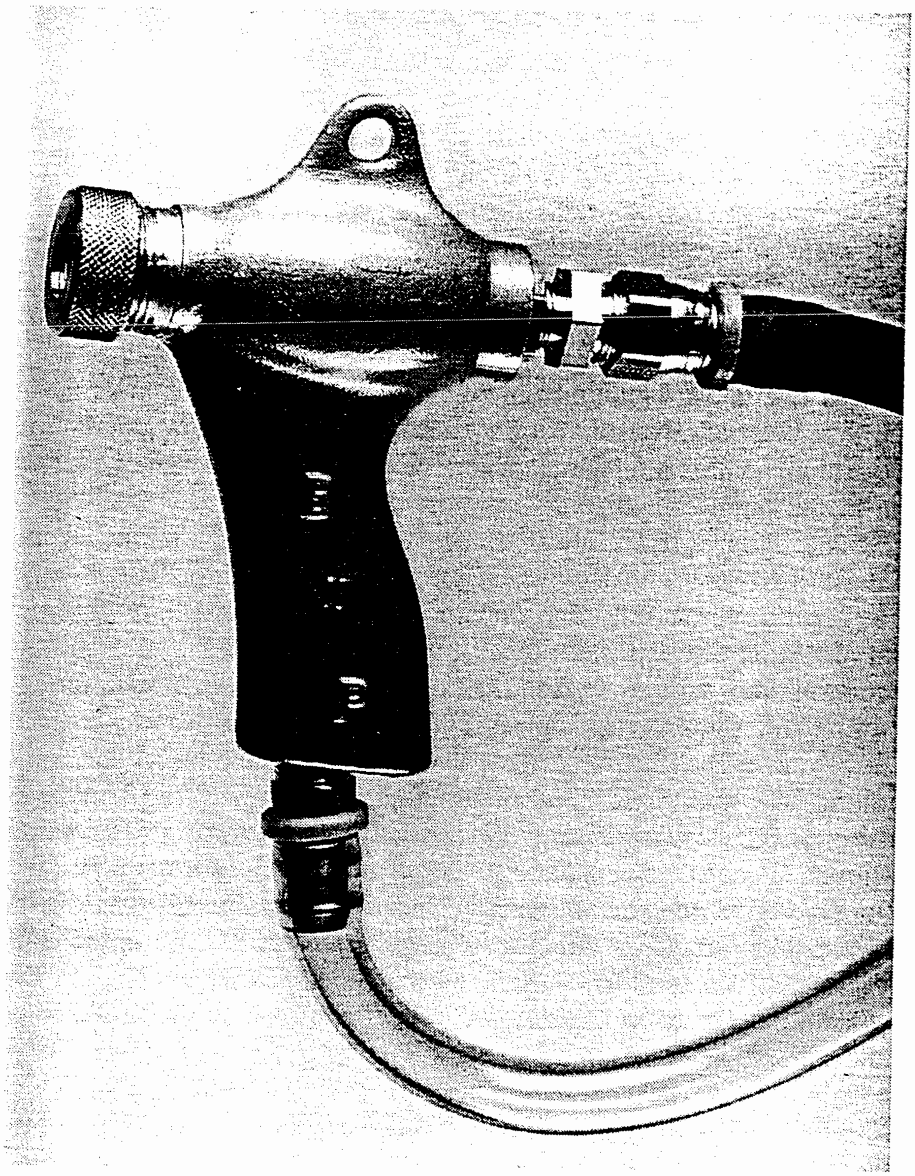

Fig. 2. Suction-type blast gun.

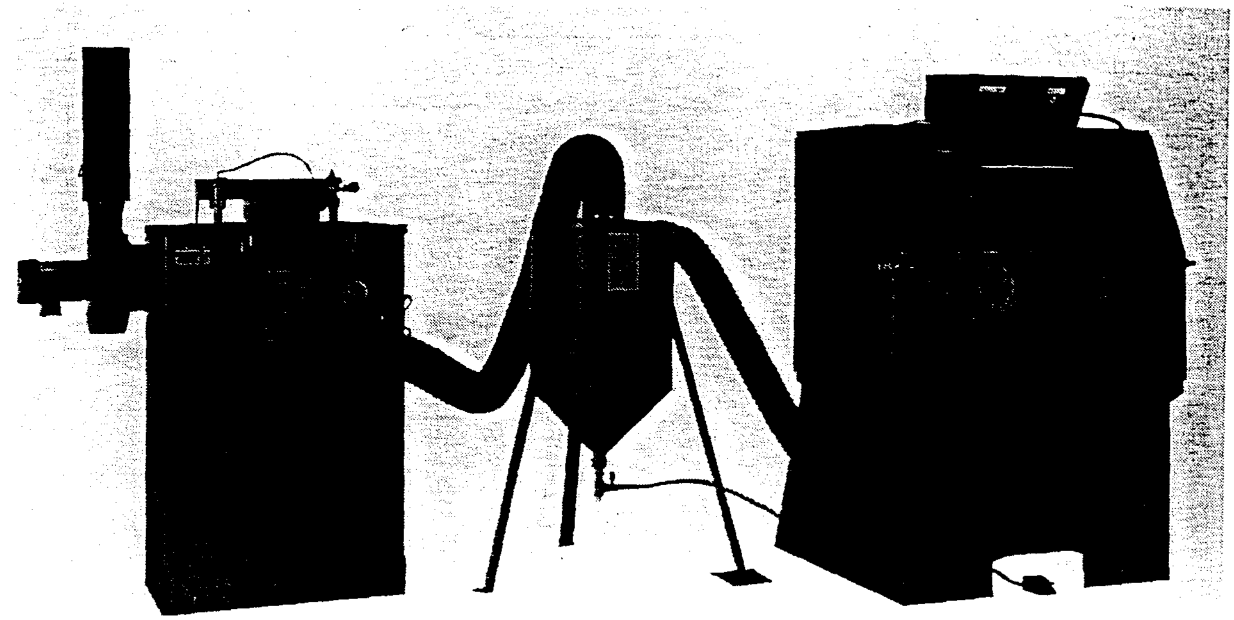

Fig. 3. Air-blast system.

flowing through the gun body from the air jet will develop a drawing action. This brings abrasive up through the abrasive hose into the gun body, where it is accelerated through the nozzle.

Suction blasting yields one-fourth to one-third the velocity and surface impact of pressure blasting. Consequently, suction blasting is more appropriate for light to moderate applications. More popular uses center around soft sophisticated metals where mild deburring, light shot peening, and thin scale removal are required without deep penetration of the base metal. As a typical example, aluminum, titanium, and magnesium automotive and aircraft parts are suction blasted.

Pressure blast systems are easily distinguishable from suction types by the use of one hose, as opposed to two hoses, to feed the nozzle. Air and abrasive travel through a single blast hose at high air pressure and rapid speed, resulting in intense surface impact.

VENTILATED ENCLOSURES

A wide variety of abrasive blasting enclosures are available to accommodate part sizes, cleaning or treatment requirements, production rates, and budgets. Blast enclosure methods include airless blasting (centrifugal wheels), water blasting, and dry air blasting. This article focuses on dry air blasting enclosures and equipment.

Blast Cabinets

Air-blast enclosures start with simple, manually operated blast cabinets (see Fig. 3). These cabinets range in standard sizes from 24-in. wide by 24-in. long (600 × 600 mm) to 72-in. wide by 72-in. long (1,800 × 1,800 mm). Typically, they are equipped with one operator station, which includes a sealed pair of gloves, a wide viewing window, and lights. Inexpensive, light duty cabinets are equipped only with dust collectors. They do not have media cleaning or efficient screening components. Generally, light duty cabinets are used for infrequent blasting applications where cleaning the media after each blast cycle is not a necessity. Applications where a cabinet may be used more than an hour per day, and when reuse of contaminated media is not acceptable, require abrasive reclaimer/screening equipment.

Blast cabinets evolve from simple, manually operated units to much more sophisticated automated systems. Systems are designed around part shapes and production quantities to produce consistent, precise surface finishes. Parts are processed in and through cabinets as individual pieces or in bulk on motorized rubber belts, roller conveyors, hanger conveyors, single turntables, and indexing tables with integral satellite turntables. Computer programmable, multiple-nozzle carriages move over the parts in multiaxis motions to cover the entire shape of the part. Microprocessors control and monitor abrasive media flow, nozzle air pressure, and dust collector efficiency. For example, system computers precisely program nozzle distance, intensity, and dwell time in highly sensitive aircraft turbine blade shot peening applications. Blast systems are designed to feed and recycle accurately clean media ranging from very fine glass bead to coarse steel grit. Blast cabinets can be designed to accommodate an extremely wide variety of surface finishing and production requirements.

Blast Rooms

Blast rooms are designed and constructed to allow operators to blast within an enclosure. With few exceptions, high production, pressure blasting is performed inside this type of enclosure. Rooms must be engineered to withstand the powerful nozzle blast and rebounding abrasive from the parts being cleaned. Walls, ceilings, and doors are usually built with heavy gauge steel, and sealed to prevent escape of abrasive and dust. Properly engineered lighting is essential for operators to see the results of their work clearly. Lighting is normally exterior mounted to avoid damage from abrasive impact.

There are many choices on abrasive recovery and recycling systems inside blast rooms. There are three basic recovery categories: floor hoppers, pneumatic, and mechanical. The choice is largely influenced by the type of abrasive, production demands, and budget limitations.

Floor hoppers are small collection hoppers measuring about 3 feet by 3 feet (900 × 900 mm), recessed in a floor pit conveniently located on one side of the room. The bottom of the hopper is attached to a bucket elevator installed outside of the room. The bucket elevator unloads into an abrasive cleaner/storage assembly, which is mounted over a pressure blast machine. In operation, abrasive is swept or shoveled into the grated floor hopper, carried up by the elevator, mechanically screened and air washed by the abrasive cleaning unit, and stored above the blast machine for reuse. This economical type of recovery system is ideal for facilities where blasting takes place occasionally.

Pneumatic recovery systems are designed to recover and clean fine, lightweight media. Applications using glass bead, fine mesh aluminum oxide, plastic, and agricultural abrasive, such as walnut shell, are more effectively reclaimed by the pneumatic vacuum process. Pneumatic systems consist of a series of small 12 in. by 12 in. (300 × 300 mm) hoppers covering the entire room floor area. The bottom of the hoppers attach to parallel conveying ducts, which connect to a master duct leading up to the inlet of the media reclaimer. The reclaimer, mounted over the pressure blast machine, centrifugally cleans and screens media for reuse (see pneumatic reclaimer section for additional information). Partial floor-sized pneumatic systems are available where complete floor recovery is not required.

Mechanical recovery systems work best with medium and heavy abrasives, especially when steel grit and steel shot are used. Several design concepts are available on the market featuring wiper vanes, oscillating pans, and screw conveyors. All the systems are covered with steel grating to support weight loads. Each design has certain advantages depending on the abrasive and application.

Wiper vane systems offer the most versatility on abrasives due to the conveying method (see Fig. 4). Steel vanes are powered by pneumatic drive cylinders in forward and backward strokes. A series of vanes push abrasive on the forward stroke. On the back stroke, the vanes tilt up and ride over abrasive on the floor. Sequencing of the vanes pushes abrasive into a vane cross conveyor and on to a bucket elevator positioned at the end. Vanes can easily handle any type of angular abrasive that is not too fine. Wiper vane systems are only offered in full floor size of the room.

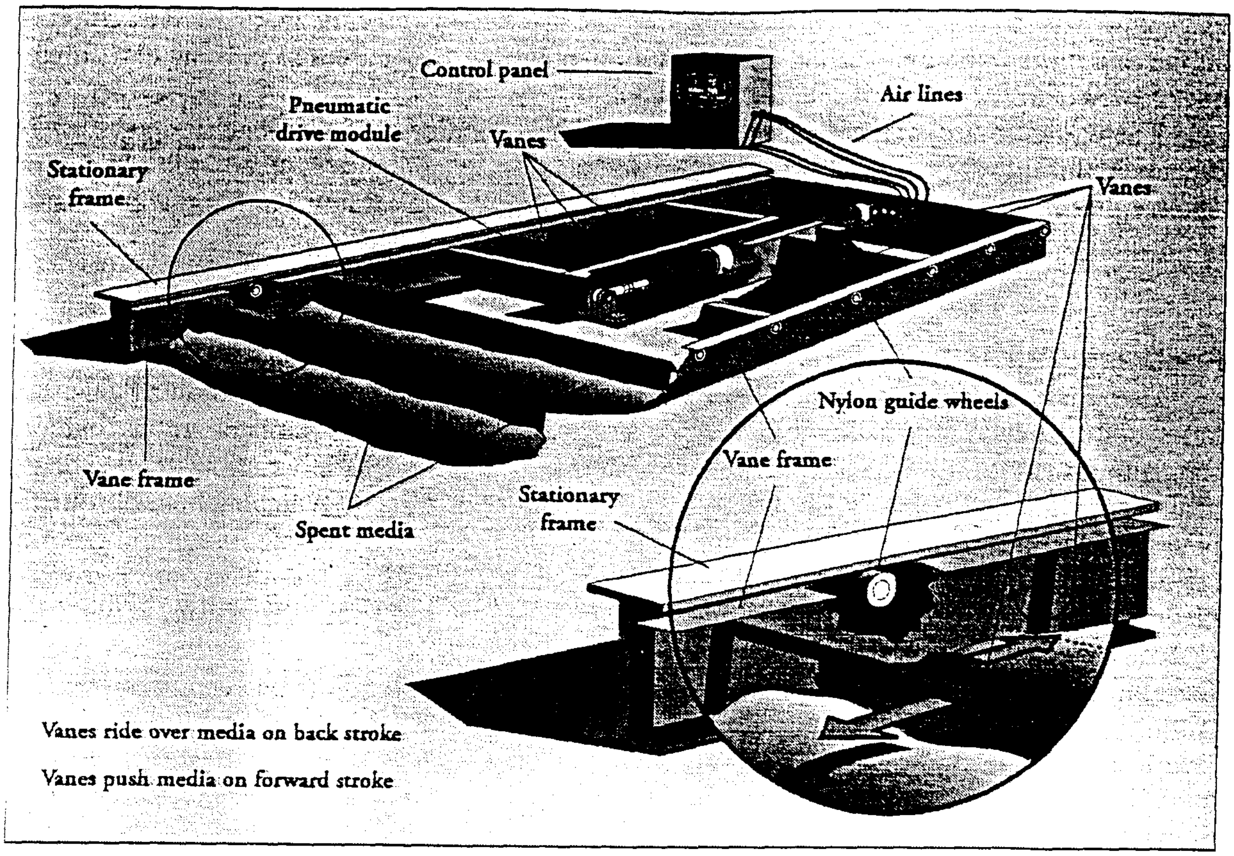

Fig. 4. Wiper vane system offers efficient, low profile recovery, ease of installation, and low maintenance.

Oscillating pans are supplied at various lengths in 3-, 4-, or 5-ft (900, 1,200, or 1,500 mm) wide sections. The steel pan in each section is hung by link chain and is oscillated back and forth by eccentric cams. A central screw conveyor collects and delivers abrasive from the pans to an outside bucket elevator. Abrasive is cleaned and stored in an abrasive cleaner as described in the wiper vane system. A single small electric motor operates all the cams in an average-size floor. This system is designed to handle coarse, angular abrasive. It is available for partial floor recovery areas at any combination of width sizes to accommodate economic limitations.

The screw conveyor system's primary advantages are abrasive recovery volume, speed, and distance. On long length blast rooms [over 50 feet (15 meters)], a screw conveyor will move greater amounts of abrasive faster than by other methods. This system consists of rows of motor-driven screw augers mounted in steel troughs, covered with steel grating. The floor augers connect to a cross collection auger, which takes abrasive to the inlet of a bucket elevator. The bucket elevator, abrasive cleaner, and blast machine are the same equipment as used with the other mechanical recovery systems previously described. The versatility of this system allows any number of screw conveyor sections to be placed anywhere in the floor area.

Blast Room Parts Handling Options

Materials may be brought into blast rooms by many different methods. Hand trucks and small wheeled carts are used to handle lightweight parts. Heavier parts are transported by forklift trucks. There are, however, several options available to reduce handling time and increase production. One common option is a monorail mounted on the blast room ceiling, using a pneumatic or electric hoist to lift, carry, and place parts.

Another popular option is steel-decked work cars riding on rubber-tired wheels or steel shells. The steel wheels are often the flanged railroad type of wheel, which allows them to be used with rail tracks. Work car wheels may be driven by pneumatic or electric motors, although a more common method is to use motor-powered steel cables to pull the carts in and out of the room.

There are many other material handling methods designed of specific parts to be processed through the room. A few examples are steel roller conveyors, rubber belt conveyors, "cherry picker" hoists, cranes, and large turntables. The choice of parts handling is predicated on desired production speed and cost justification.

Pneumatic Reclaimers

Pneumatic abrasive reclaimers provide one of the best methods of removing dust and large contaminants from recycled media. Reclaimers, sometimes referred to as cyclone separators, work on the principle of centrifugal force to spin media at a rapid rate to separate heavy particles from light particles. Media are drawn up through vacuum hoses from the bottom of cabinets by means of electrically powered impellors. The media-spinning action begins as soon as the media enters the reclaimer. Heavier particles and debris are thrown to the outer perimeter of the reclaimer while lightweight dust particles circle around the reclaimer center, where a suction tube connected to the dust collector pulls the dust out. Heavy reusable particles and debris swirl downward into a meshed screen. The screen captures debris and allows heavy media to pass through to a storage area for reuse.

There are two basic reclaimer designs—push through and pull through. On push through, the blower and motor are installed on top of the reclaimer. This design is primarily furnished on smaller, one-operator cabinets. On pull-through reclaimers, the blower and motor are assembled on the clean air side of the dust collector. This design draws air from the reclaimer through the vacuum hose and captures fine particles in the dust collector filters. Multi-operator cabinets, large cabinets, and blast rooms utilize the pull-through concept.

Reclaimers are carefully sized to accommodate the cabinet and blast room dimensions, number and size of blast nozzles, and the type of media. Blowers and motors are also sized to correspond with the reclaimer requirements. Reclaimers and blowers are air-flow rated in cubic feet per minute (cfm) with the smallest rating beginning at 300 cfm (8.5 m^3/min).

Dust Collectors

Efficient dust collectors are vitally important for all blasting enclosures. In addition to capturing dust, they must effectively prevent any unacceptable emission into the surrounding atmosphere. Proper dust control eliminates the danger of respiratory injury to personnel, and avoids contaminating nearby machinery. It is an absolute necessity to use high-quality dust collectors specifically engineered for abrasive blasting applications.

Some of the major considerations for choosing a dust collector are the dust particles that will be generated from the abrasive and the material to be removed from the surface, air flow and air volume requirements, and the amount of dust loading the collector must handle. The composition and construction of the unit's filters must be designed to accommodate wide variations found in different blasting processes.

Dust collector filters are available in a variety of types and materials. The selection of types is generally on envelope, tubular, or cartridge. Envelope filters are flat, rectangular, cloth segments, which are assembled side by side in a collector housing. Tubular filters are cylindrical, attach to collector housing tube plates at each end, and come in many different lengths. Cartridge filters are round and compact with evenly spaced pleats of cellulose fiber material (see Fig. 5). Each segment, tube, and cartridge, provides a specific amount of square feet of filtering material. Engineering specifications on the blasting system determine the required number of square feet of filter materials, which, in turn, gives the number of segments, tubes, or cartridges required in the dust collector.

Another factor in filter specifications is the "air-to-cloth ratio" requirement. "Cloth" is used as a generic term, whether or not the filter material is cloth. Blasting applications, which

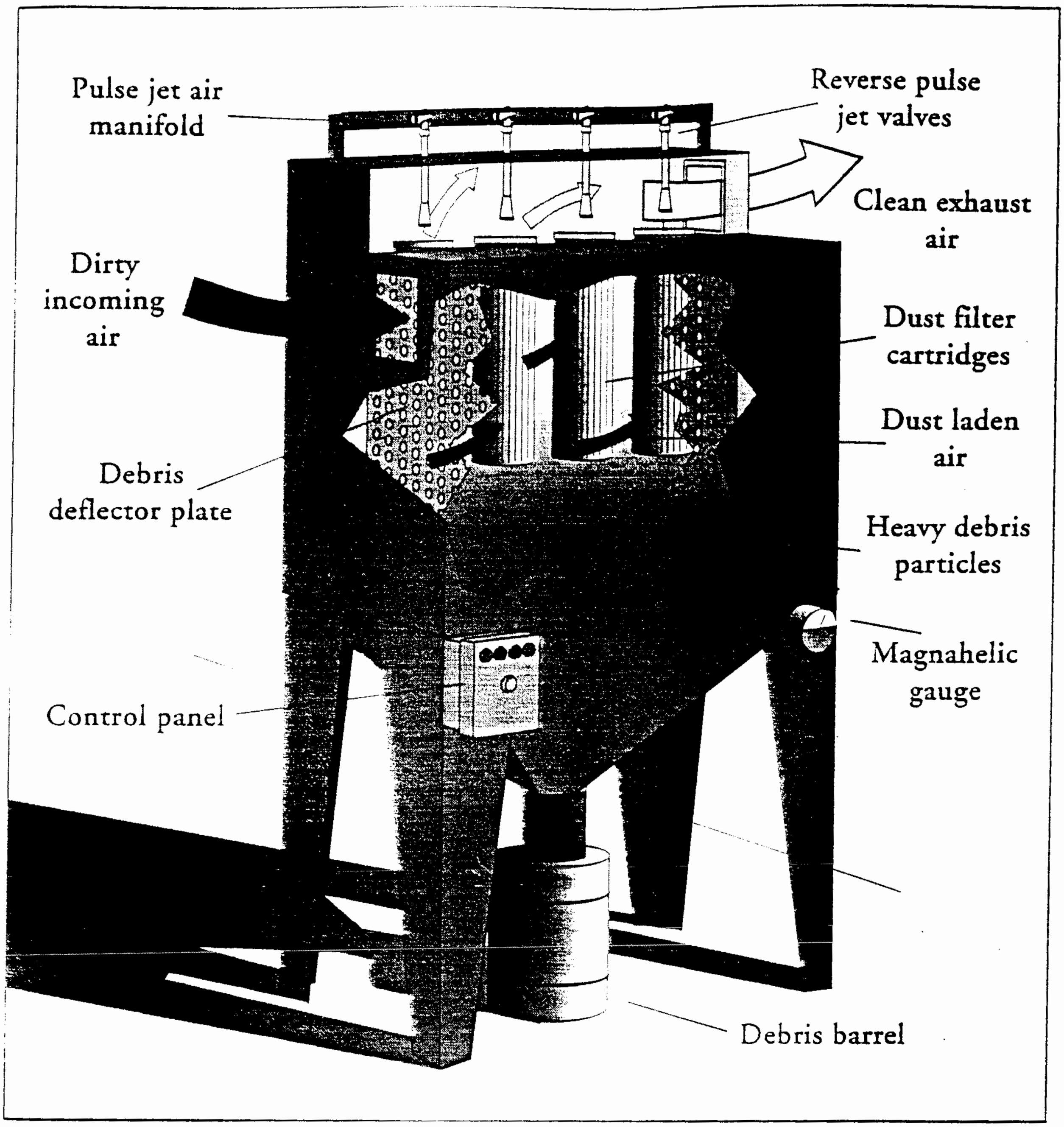

Fig. 5. Cartridge dust collector cleans its filter elements with periodic blasts of compressed air.

include the number of blast guns, type of abrasive, composition of removed substance, and so on, dictate the proper ratios. There are also federal, state, and/or local regulations with which to comply. In abrasive blasting applications, ratios usually range from 5 cfm of air to 1 foot of cloth (designated as 5:1) to 2 cfm of air to 1 foot of cloth (2:1). The lower the number of cfm, the more filter material is required. As a simple example, on a standard blast cabinet requiring 600 cfm of ventilation air, and where an air-to-cloth ratio of 5:1 is acceptable, the dust collector will be furnished with 120 or more square feet of filter material.

COMPRESSED AIR

A standard abrasive blasting system is totally powered by compressed air, whether it is a cabinet or blast room. There are exceptions where some accessory items are run by electricity, but for most systems, compressed air operates valves, pressurizes blast machines, conveys abrasive to nozzles, provides operator breathing air, and runs additional ancillary equipment. Compressed air is a critical component of blast systems because its energy generation dictates the amount of work that will be done on any given surface.

Pressure and Volume

So many times we hear the statement, "I have plenty of air ... I have 100 pounds of pressure." High pressure is great, but it is only one-half of the energy equation. Along with pressure, there has to be air volume. A 100-hp (75 kw) compressor can produce 100 psi (700 kPa), but so can a small 1-hp (0.75 kw) electric compressor. A 1-hp (0.75 kw) compressor will develop between 4 and 4.5 cfm of air (0.11–0.12 m^3/min); a 100-hp (75 kw) unit will generate between 400 and 450 cfm of air (11.3–12.7 m^3/min). Obviously, the difference between the two compressors is the air volume they are capable of producing.

Pressure and volume work hand in hand. In abrasive blasting operations, the higher the pressure, the higher the volume consumed. If the volume of air is not available to accommodate the pressure, the desired pressure will not be attained. To illustrate this point in pressure blast systems, a ⅜-in. (9.5 mm) nozzle requires approximately 200 cfm at 100 psi (5.6 m^3/min at 700 kPa). If a 150 cfm (4.2 m^3/min) compressor is hooked up to a blast system using a ⅜-in. (9.5 mm) nozzle, the maximum amount of pressure the compressor can produce is about 70 psi (490 kPa). The 150-cfm (4.2 m^3/min) compressor simply does not have the volume capacity to supply 100 psi (700 kPa) to a ⅜-in. (9.5 mm) nozzle.

There is rarely too much air volume, but air pressure is another story. Pressure blast machines and their related components and accessories are built to operate within specific pressure ratings. Standard blast machines are fabricated for working pressures up to 125 psi (880 kPa). Although some of the blast components have higher pressure ratings (i.e., blast hose), pressure to the entire system should not exceed the approved pressure rating of the blast machine. (Note: Some European machines are built for 180 psi (1,200 kPa) as standard; therefore, air compressors and ancillary equipment are rated accordingly.)

A common question is what pressure is needed for high-production pressure blasting. For most applications, 90–100 psi (630–700 kPa) works well when hard, sharp abrasives in standard mesh sizes are used. The 100-psi (700 kPa) level was established long ago as the maximum pressure. Using a coarse, extremely sharp abrasive, such as aluminum oxide, it is often better to set pressures in the 70–80 psi (490–560 kPa) range because of deep surface penetration by the abrasive's sharpness. Proper pressure is a determination based on surface condition, required surface finish, and selection of abrasive.

In cabinets using the suction principle, the normal maximum pressure is 80 psi (560 kPa) due to the use of fine, soft blasting media, and the close proximity of the nozzle to the part. When blasting on delicate materials, the pressure may be reduced to as low as 30 psi (210 kpa) to avoid damage to the parts. Even in suction blasting, however, air volume is equally important.

Compressor Air Lines

The majority of applications for metal air lines are stationary, in-plant blasting systems where lines are permanently placed. Although there are flow advantages, metal line air requires similar filtering care as any other method of conveying air. Condensation builds up rapidly in the pipe during the conversion of hot compressor air to cold expansion in pipe lines. Drainage valves should be installed in piping, just before entering blast system filters, to bleed accumulated line water. As steel pipe lines age, rust and scale particles are carried in the air flow to blast machines. Consequently, high-efficiency filters are needed to remove moisture, oil mists, and particulate matter.

The only drawbacks to permanent piping are distance and turns. Many plants install compressors far from blasting sites so air must travel several hundred feet before entering

Table II. Recommended Hose Diameters

Nozzle Orifice Size, in. (mm)	*Minimum Hose Diameter, in. (mm)*
3/16 (5)	3/4 (19)
1/4 (6.5)	1 (25)
5/16 (8)	1-1/4 (32)
3/8 (9.5)	1-1/2 (38)
7/16 (11)	2 (50)
1/2 (12.5)	2 (50)
5/8 (16)	2-1/2 (64)
3/4 (19)	3 (76)

blast systems. There is pressure loss even through smooth piping and, if the distance is very long, substantial pressure drops occur. To overcome this problem, larger-than-normal pipe should be installed. The turns and bends in the pipe cause pressure loss, as well. Arrange piping to avoid as many sharp turns as possible and, when turns must be made, try to install two 45° elbows rather than one 90° elbow. Gradual bending of air flow is less detrimental to pressure than are radical turns.

Sizing air lines is critical to utilizing compressor power fully, which ultimately affects blast equipment performance. Air line sizes must be consistent with compressor fittings to allow a smooth transition of flow at pressures and volumes required to support nozzles. Determining air line size follows the same rule as calculating compressor air outlets ... *hose inner diameter should be a minimum of four times the nozzle orifice size.* This rule applies to applications where air lines are no longer than 100 feet (30 meters) between compressors and blast machines. Use Table II to ascertain air line inner diameters.

PRESSURE BLAST MACHINES

A blast machine is primarily a storage device to hold abrasive for release into an air stream (see Fig. 6). Although it appears to be a little more than a steel tank, there are a number of integral parts that make sizable differences in safety, convenience, and efficiency. Poorly designed blast machines are one of the biggest culprits responsible for lost air flow and pressure. Basic engineering logic reveals that the greatest air flow efficiency takes place when restrictions are eliminated and friction losses are kept to a minimum.

In the United States, blast machines, being pressurized containers, must be fabricated, tested, and approved according to American Society of Mechanical Engineers (ASME) standards. The type of steel and welding methods is specified by ASME pressure vessel codes. Most commonly, blast machines are rated and approved at working pressure of 125 psi (880 kPa). ASME's standard requires a pressure safety margin of 50% above working pressure, thus, dictating hydrostatic testing at a minimum of 188 psi (1300 kPa).

Machine design should avoid complicated configurations that deter from smooth abrasive flow through the system. Gravity-fed blast machines have proven to be a simple, trouble-free scheme when fitted with concave heads (tops) and conical bottoms. The machine top should be equipped with a semi-elliptical head, which stores more reserve abrasive and provides greater slope for abrasive flow into the machine than the conventional flat-dished head. Most heavy granular abrasives have an approximate 32° angle of repose; consequently, cone bottoms should be shaped at no less than a 35° angle to ensure complete and uninterrupted abrasive flow. Machines used with lighter media, such as glass bead and plastic, require a steeper angle of 60° on the bottom. Using lightweight media in flat or 35° outlets will cause continual flow problems, especially with a moist air supply.

Special attention must be paid to the outside plumbing of blast machines because this is where the majority of air flow and air pressure is lost. Actually, there is always friction-

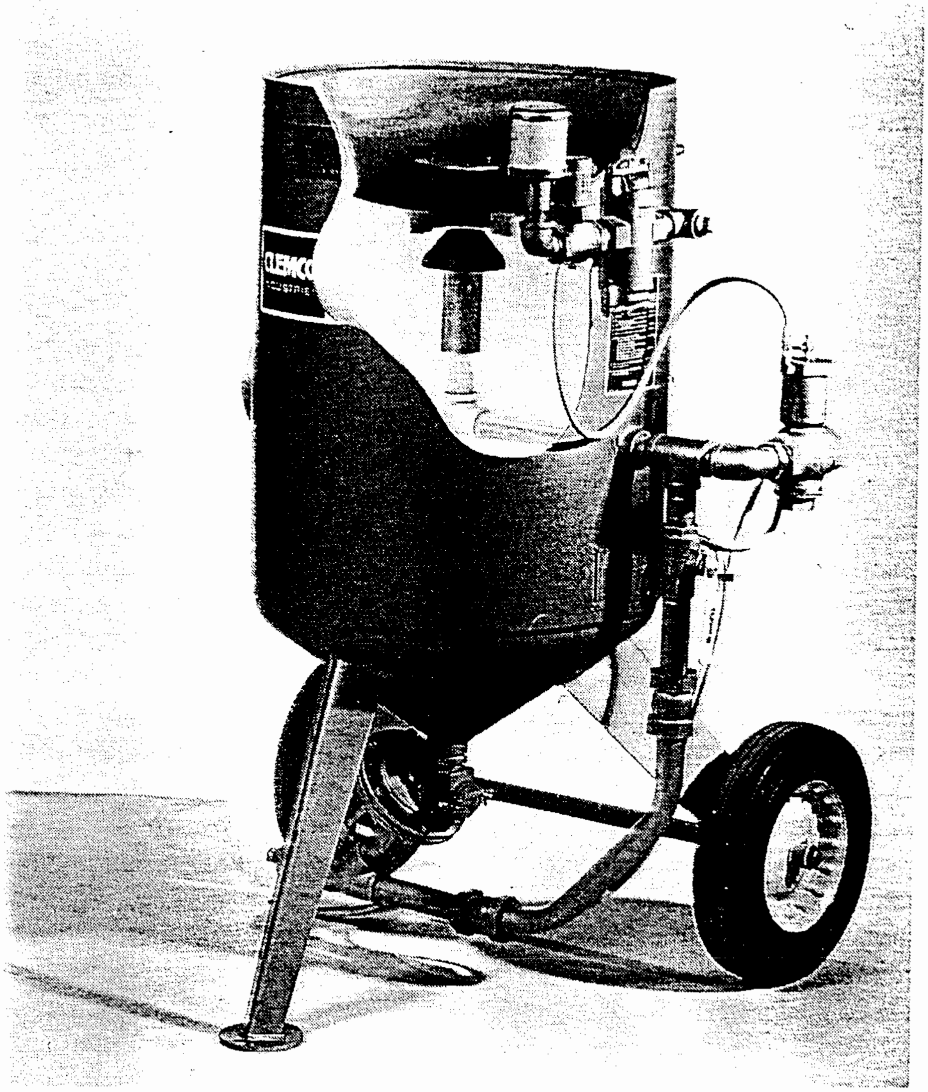

Fig. 6. Pressure blast machine.

generated pressure loss in any size pipe, but the key is to minimize loss. Full airflow at high pressure in 1¼-in. (32 mm) piping cannot be attained if it is being fed through a ¾-in. (19 mm) valve, because the small valve is starving the larger piping of air.

When working with air hose, blast hose, air piping, air valves, and for that matter, anything in an air line, think *big ... very big* (see Fig. 7). Any restriction or obstruction will

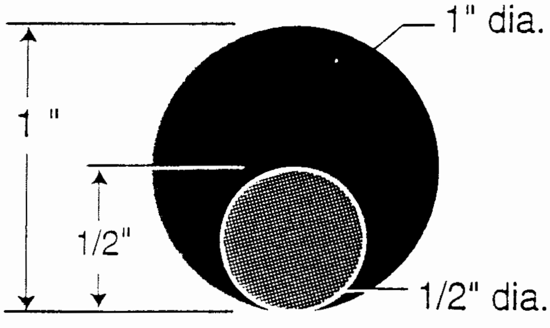

Fig. 7. When working with air hose, blast hose, air piping, air valves, or anything in the air line, think big. Half the diameter is only a quarter of the surface area (1-in. diameter is 0.8 in.^{2}, whereas 0.5 in. is only 0.20 in.^{2}).

cause tremendous loss of costly air supply; therefore, it is wise to check every fitting and valve size in the entire piping arrangement.

Abrasive Metering Valves

Regulating abrasive into an air stream is a highly critical aspect of surface impact performance. The method and accuracy of metering abrasive have dramatic effects on production speed and cleaning efficiency. The primary objective of an abrasive metering valve is to use the energy of every abrasive particle to work the surface as intended. When too little abrasive is used, particles are widely spread over the blast area, which slows down blasting production and leaves untouched surface voids. Too much abrasive is equally detrimental to cleaning rates because excessive particles collide with each other, rather than being uniformly dispersed over the blast pattern area. Exorbitant abrasive usage also results in costly waste and labor. Consequently, it just makes good sense to utilize well-built, properly designed, metering valves.

A logical approach to feeding abrasive into an air stream is to bring it in at a 45° angle in the same flow direction as the air. This concept allows a natural blending of air and abrasive material without creating flow obstacles. The overall result is a smooth, steady supply of abrasive for consistent blast patterns on the surface.

Remote Controls

All abrasive blast machines must be furnished with automatic remote controls that are designed to shut off machines as quickly as possible. In the United States, installation of remote controls is an OSHA regulation (29 CFR 1910.244). The device (control handle) that activates remote control valves must be located at the nozzle and must be used correctly by the blaster. Using blast machines without remote controls is a dangerous and unacceptable practice that may result in serious injury to blasters and other personnel in the immediate vicinity.

In addition to obvious safety features, there are other benefits to utilizing remote controls. Quick start and stop response offered by remote control systems avoids substantial waste of abrasive. If a nozzle has to be pointed in the air while waiting for someone else to shut off the machine or while the blaster is repositioning on scaffolding, good abrasive is being squandered. Another labor-saving advantage is eliminating the necessity of a helper who tends the blast machine.

Blast Hose

Hose and hose fittings are victims of rapid wear and tear by the very nature of their exposure in an abrasive blasting system. Hose, in particular, is especially vulnerable due to the cutting action of high-velocity abrasive on the inside. On hose fittings, wear is seldom a problem, but rough handling shortens their useful life through breakage and deformation. Procuring appropriately sized, top-quality blast hose and fittings and installing them properly is the most advantageous approach to keeping costs in line and production at a high level.

Hose must be specifically manufactured for abrasive blasting. It should have thick-walled internal rubber tube supported by fabric, protected by a durable outer cover, and rated at an appropriate working pressure. Rubber tubes must be treated with static-dissipating compound for the comfort and safety of the operator. Typical wall thickness of blast hose tube is ¼ in. (6.3 mm). Thin-walled hose tubes only 3⁄16-in. (4.7 mm) thick are often found in super flexible blast hose where customers prefer more elastic hose movement.

The sole purpose of blast hose is to convey air-driven abrasive from the blast machine to the nozzle. Hose should have a sufficient inner diameter to allow unrestricted particle movement. It should be no longer than necessary to carry abrasive from the machine to the nozzle.

There is a very simple formula to use when selecting blast hose. It starts with the size of the nozzle orifice and continues back to the machine piping. The formula is: *blast hose inner diameter should be three to four times the size of the nozzle orifice*. Where possible, choose the four times number.

Couplings and Hose Ends

Blast hose couplings and hose ends are available in a variety of materials and configurations. Much like blast hose, couplings and hose ends must be designed and manufactured to withstand the rigors of rough service.

Generally, hose couplings are manufactured from brass alloy, aluminum alloy, or nylon materials. Each material serves a particular purpose, although there is an overlap of purpose based on job applications. Brass is ideal for rough and tough usage. Aluminum is lightweight but less durable than the other two materials. Nylon offers the lightweight feature of aluminum and durability of brass, in addition to precise dimensional advantages.

For the most part, there is an industry standard on the method of interconnecting hose couplings. Locking lugs (two) on every coupling are identically formed to allow any two couplings to be firmly connected and, with a quarter of a turn, locked into place. Universal-designed locking lugs are produced on couplings for blast hoses ranging from ½-in. to 1½-in. (13–38 mm) inside diameter. Standardized lugs are convenient in that variously sized hose can be coupled together without the necessity of an assortment of couplings.

Every coupling is supplied with a rubber gasket to seal against air and abrasive leakage. When two couplings are placed together for connection, gaskets in each coupling align and compress as the couplings are twisted into the locked position.

Specially designed safety cables for blast hose are available to prevent injury in the event two hoses disengage. A second safety feature for hose couplings is safety pins, which eliminate accidental twisting from a locked position.

BLAST NOZZLES

Performance at the blast nozzle reveals whether or not all of the previous requirements for air and abrasive flow have been correctly followed. The objective of everything installed between the air compressor and the nozzle has been to convey a steady supply of abrasive at adequate pressure to the nozzle.

Nozzles are versatile in performance. They can convert air-driven abrasive into a highly accelerated cutting force that can tackle the toughest application. They can also decelerate abrasive into a low-flow process that can gently strip paint away from soft surfaces. Choice of size, type, and shape of nozzles becomes an important decision due to the effect on production speed and desired appearance of the end product.

Nozzle Materials

There are various types of nozzle materials that primarily effect wear life. Wear life, however, is not simply a matter of how long a nozzle will last; it is a critical element affecting air flow. The nozzle orifice is the determining factor for air volume usage; that is, a certain-sized orifice will pass a certain volume of air. As the orifice wears, it will require increases in air volume to maintain 100 psi (689 kPa). For example, a nozzle with a ⅜-in. (9.5 mm) orifice operating at 100 psi (689 kPa) requires air volume of 196 cfm (5.5 m^3/min). When the nozzle orifice enlarges by 1/16 in. (1.5 mm), the air volume required to maintain 100 psi (689 kPa) is 254 cfm (7.2 m^3/min). A tiny *1/16th of an inch (1½ millimeter wear)* on the nozzle orifice *increases the air volume requirement by 30%!* All the more reason to choose nozzle materials that provide the best possible wear resistance for prolonged productive results.

Table III. Effect of Orifice Size on Area

Nozzle No.	*Orifice, in. (mm)*	*Area, in.^{2} (mm^2)*	*Area Increase*
4	1/4 (6.5)	0.05 (3.2)	—
5	5/16 (8.0)	0.08 (5.2)	60% larger than No. 4
6	3/8 (9.5)	0.11 (7.1)	38% larger than No. 5
7	7/16 (11.0)	0.15 (9.7)	36% larger than No. 6
8	1/2 (12.5)	0.20 (12.9)	33% larger than No. 7

Available nozzle materials are cast iron, ceramic, tungsten carbide, silicon carbide, and boron carbide. Cast iron is rarely used today because of its rapid wear, which is typically 6–8 hours. Ceramic is commonly used with small, light duty equipment and with blast cabinets where nonaggressive abrasive is used. Carbide-type nozzles are the most popular choice on the great majority of blasting applications due to their long life characteristics.

Nozzle Shape

Since the advent of abrasive blasting, the shape of nozzles incorporated a tapered entrance leading into a straight barrel of various lengths. With straight barreled nozzles, the center of the blast pattern is hit with excessively heavy concentrations of abrasive while the outer perimeter gets only a spattering of abrasive coverage. Straight barreled nozzles continue to be used, but generally only on low-production machines or in blast cabinets where the distance between parts and nozzles is very close.

A more effective nozzle shape is the venturi design. In the venturi configuration, an engineered converge–diverge concept is calculated to accelerate abrasive particles to their maximum velocity. The length and diameter of the cone-shaped entrance are mathematically calculated to correspond to the orifice size and to the flared length and diameter of the exit end. Each size of nozzle has its own shape dimensions—no two sizes are the same. Abrasive enters the converging end of the nozzle, funnels through the orifice, and rapidly expands into a high-powered stream through the diverging exit end of the nozzle. At 100 psi (689 kPa) nozzle pressure, the velocity at the end of the nozzle reaches 660 feet per second (200 meters per second)—nearly the speed of sound. By comparison, a straight barreled nozzle velocity is 318 ft/sec (97 m/sec), which is less than half of the venturi's velocity.

Nozzle Orifice

Nozzle orifices dictate the amount of compressed air required for blast machine assemblies. The larger the orifice, the higher the production. Naturally, the largest possible nozzle should be used as long as the air compressor can support it.

The second major consideration with nozzle sizing, similar to hose and pipe, is comprehending the area of a circle and how alteration of a circle changes a blasting system's performance. When orifices wear or when nozzles of different orifice sizes are interchanged, there is a dramatic change in air requirements and abrasive consumption. Table III illustrates the effect of nozzle orifice selection or the effect of wearing an original orifice 1⁄16-in. (1.5 mm) larger.

Translating the figures in Table III into compressed air and abrasive usage, when a number 4 nozzle wears by 1⁄16 in. (1.5 mm), it will use 60% more air and abrasive than it did originally. Referring to a nozzle consumption chart (see Table IV), the percentages shown in Table III are proven to be reasonably accurate in the abrasive and air usage figures. It is easy to see how a blast system that has been equipped with an air compressor with no reserve supply of air will start to show a reduction in production as the nozzle begins to wear.

Table IV. Nozzle Chart Giving Compressor Air and Abrasive Consumption

Nozzle Orifice	Pressure at the Nozzle (psi) 50	60	70	80	90	100	125	Air (in cfm) Abrasive and Power Requirements
No. 2	11	13	15	17	18.5	20	25	Air (cfm)
(1/8 in.)	0.67	0.77	0.88	1.01	1.12	1.23	1.52	Abrasive (ft^3/hr and lb/hr)
	67	77	88	101	112	123	152	
	2.5	3	3.5	4	4.5	5	5.5	Compressor hp
No. 3	26	30	33	38	41	45	55	Air (cfm)
(3/16 in.)	1.50	1.71	1.96	2.16	2.38	2.64	3.19	Abrasive (ft^3/hr and lb/hr)
	150	171	196	216	238	264	319	
	6	7	8	9	10	10	12	Compressor hp
No. 4	47	54	61	68	74	81	98	Air (cfm)
(1/4 in.)	2.68	3.12	3.54	4.08	4.48	4.94	6.08	Abrasive (ft^3/hr and lb/hr)
	268	312	354	408	448	494	608	
	11	12	14	16	17	18	22	Compressor hp
No. 5	77	89	101	113	126	137	168	Air (cfm)
(5/16 in.)	4.68	5.34	6.04	6.72	7.40	8.12	9.82	Abrasive (ft^3/hr and lb/hr)
	468	534	604	672	740	812	982	
	18	20	23	26	28	31	37	Compressor hp
No. 6	108	126	143	161	173	196	237	Air (cfm)
(3/8 in.)	6.68	7.64	8.64	9.60	10.52	11.52	13.93	Abrasive (ft^3/hr and lb/hr)
	668	764	864	960	1052	1152	1393	
	24	28	32	36	39	44	52	Compressor hp
No. 7	147	170	194	217	240	254	314	Air (cfm)
(7/16 in.)	8.96	10.32	11.76	13.12	14.48	15.84	19.31	Abrasive (ft^3/hr and lb/hr)
	896	1032	1176	1312	1448	1584	1931	
	33	38	44	49	54	57	69	Compressor hp
No. 8	195	224	252	280	309	338	409	Air (cfm)
(1/2 in.)	11.60	13.36	15.12	16.80	18.56	20.24	24.59	Abrasive (ft^3/hr and lb/hr)
	1160	1336	1512	1680	1856	2024	2459	
	44	50	56	63	69	75	90	Compressor hp

This table provides calculated consumption rates of air and abrasive for new nozzles. When selecting a compressor, add 50% to these figures to allow for normal nozzle wear and friction loss.

OPERATOR SAFETY EQUIPMENT

Anyone working with a powerful stream of sharp particles containing some degree of foreign materials, and removing surface contaminants that may contain toxic substances, needs personal protection equipment of the highest caliber of safety and quality (see Fig. 8). Personal safety equipment for blast operators and any personnel in the blast room is an absolute necessity to prevent a variety of injuries that will occur without proper protection.

One of the more prominent components of an operator safety/comfort system is an air-fed helmet. The objectives of an air-fed helmet are to furnish the operator with clean, fresh breathing air, protect the head and face from rebounding abrasive, provide a wide field of vision, muffle excessive noise, and offer head impact protection. To accomplish these objectives, the helmet should be constructed of lightweight, high impact, molded polyethylene, which has been tested and approved to hard hat standards for construction applications (OSHA 29 CFR, 1910.135). The interior of the helmet should be furnished with an inner shell

Fig. 8. Operator safety equipment.

or inner air channel and should be configured to circulate air flow throughout the entire helmet top section, while directing a gentle air stream at the vision window to keep the lens from fogging.

Helmet Air Supply

Air furnished to helmets and hoods *must* be clean, dry, contamination free and at NIOSH prescribed pressure and volume. Simple logic dictates the need for good, clean air because it is used for breathing air, but more than that, breathing air quality is heavily regulated to precise specifications. Special attention must be paid to the source and composition of air and its required filtration system. Carefully read *all* instructional materials on *all* equipment employed in the breathing air producing and conveying system.

There are several sources for breathing air ranging from small air cylinders to large, oil-lubricated air compressors. No matter how or where air is furnished, it must comply with strict standards for high-quality breathing air. Never attach a breathing air hose to plant or any stationary fittings without first testing the quality of air in the line. breathing air quality must meet *at least* the requirements described in the Compressed Gas Association Commodity Specifications ANSI/CGA G-7.1 as specified by OSHA regulations 30 CFR, Part 11, Subpart J, paragraph 11.121 (Grade D or higher quality).

Breathing Air Filters

Air supplied to helmets and hoods must be cleansed through efficient filtering systems. It is not only a good idea to clean the air, but it is also an OSHA regulation (29 CFR, Subpart

I, 1910.134). OSHA demands that filters comply with some of the requirements for Grade D quality breathing air. The filter's role in Grade D is to remove oil mists, water vapor, and particulates larger than 0.5 micron. *Filters that do not meet these specifications should not be used for breathing air.*

There is a vast selection of filters on the market. Unfortunately, many users choose small, inadequate filters because of price rather than performance. Choosing ineffective filters is false economy, in addition to violating the OSHA regulations. Dust, dirt, and other foreign matter mixed with oil and water mists clog air passageways and sound deadening materials inside respirators. Air flow become restricted, required pressure diminishes, and operators experience unpleasant odors. The same problems occur if filters are too small to handle continuous volume and pressure of air. Poorly chosen filters result in frequent and costly maintenance of respirators, as well as reducing safety levels for operators.

High capacity, super efficient filters should be installed in breathing air systems. These filters should be designed with filter cartridges that can be quickly replaced. Filter bodies should be engineered to handle air volume and pressure by allowing inlet air to expand, cool, and slow down the velocity prior to entering filtering media. Filters must be equipped with pressure regulators and gauges, not only to set required air pressure, but also to use the gauge to indicate when cartridges need replacement. Gauges, installed on the clean air side of filters, will show declining readings when cartridges begin to saturate with liquid and solid matter. As an extra precaution, pressure relief valves are mounted on filters to prevent any change of excessive pressure.

Carbon Monoxide Alarms and Converters

The greatest danger associated with lubricated air compressors for breathing air is carbon monoxide. Very simply, carbon monoxide is produced by overheated compressors, which burn lubricating oil to the point where carbon monoxide gas is formed in the compressor compartment and fed into the air line. *Carbon monoxide kills*; therefore, safety steps must be implemented to prevent exposure to this deadly gas. First, air compressors must be serviced at the manufacturer's recommended intervals. Second, compressors must be equipped with overheating shut-off devices and/or carbon monoxide alarms. If only an overheating alarm is used, the air must be frequently tested for carbon monoxide. Refer to OSHA regulation 29 CFR, Subpart I, 1910.134 for specific details.

Carbon monoxide detection equipment is available to perform two different functions. One method is to monitor supply air and set off an alarm if carbon monoxide reaches an unacceptable level. The other method is a sophisticated system that is designed to convert carbon monoxide to carbon dioxide, a less dangerous gas.

Protective Clothing

Abrasive moving at high velocity can inflict serious injury upon unprotected operators performing blasting jobs; therefore, it is essential to furnish them with protective clothing. OSHA regulation 29 CFR, Subpart I, 1910.94 and 1910.134 states that operators should wear heavy duty clothing, canvas or leather gloves, and safety shoes. Lightweight clothing simply will not provide sufficient protection. Heavy duty clothing is effective against ricocheting abrasive and it will afford adequate protection from momentary direct blasts of high-speed, sharp abrasive.

OPERATOR TRAINING

Without question, the most important element of a manually operated blasting system is the blaster. The finest equipment on the market will not perform to its greatest potential without blasters who are fully trained on equipment and totally knowledgeable on concepts.

Just as critical to production output is the safety factor. Blasting is a powerful cleaning method, which requires mandatory attention to safety procedures for operators and job site personnel.

Although abrasive blasting is not a highly technical vocation, a considerable level of operator skill is absolutely necessary to achieve the best results. Using spray painting as a comparative scenario, no one would consider taking people off the street, handing them spray guns, and telling them to start painting a bridge. They would not know how to set up the paint spray equipment with the proper amount of air and paint, or how to apply paint in an even layer over the entire surface without excessive overlapping and missed spots, or how to clean and maintain the equipment to prevent costly repairs. The consequence would be a devastating failure of the paint job and profit-robbing rework.

The same scenario would be true with abrasive blasting, with the addition of a far greater chance for personal injury. Ill-trained blasters will not accomplish satisfactory results on production rates or achieve required surface finishes, if they do not know how to utilize the equipment to its full potential. More importantly, they could seriously injure themselves if they are not properly educated on blasting processes, and they are not instructed on mandated safety procedures. Many painting and coating jobs have had to be redone at great expense due to poor blasting work. It simply makes no sense to jeopardize any job or subject anyone to possible injury by using unprepared personnel. Conversely, workers who have attained a high degree of expertise in the blasting process will produce predictable profits under safe working environments, and will ultimately contribute to the overall success of their companies.

A thorough training program is not simply how to use the equipment. In order for operators to become truly skillful with their job, they must know the purpose of the job, their objectives, and how their performance will be measured. They must learn about surfaces they will be blasting and what results are required. They must learn about abrasive, air pressure, air volume, and how these interrelate to meet specifications on surface cleanliness and profile. Above all, they must be totally familiar with the equipment and how to maintain it in top condition for maximum efficiency and safety.

BLASTING ABRASIVE

Basic Properties

Abrasive—air compressors power it, blast machines store and meter it, blast hoses transport it, and blast nozzles accelerate it. All of these components are important elements, but it is the abrasive that does the work. If the abrasive is wrong, the end result will be wrong. Consequently, selection of abrasive is critical to obtaining the right surface finish in the right amount of time.

Unfortunately, abrasive is often chosen for economic, rather than for productive, reasons. There are far too many examples of coating failures due to the use of the wrong abrasive. Abrasive is often an expendable product, and is usually one of the higher costs in a blasting job. Conversely, a correct choice of abrasive can prove to be a tremendous cost saver because of increased blasting speed and accurate cleaning results. There is no advantage to using the best possible equipment and an inferior abrasive. The equipment simply cannot compensate for abrasive that is not designed for the work.

Use only high-quality abrasives specifically manufactured for abrasive blasting. Oversized particles will cause too deep of a penetration on the surface, which would be detrimental to coating effectiveness due to high peaks that protrude above the coating protective layer. Excessive undersized particles and tiny dust fragments will significantly reduce production speed and may neither clean the surface adequately nor create sufficient etch for coating adhesion.

All abrasives are not the same and they do not produce the same results. There are several characteristics that must be considered when selecting an abrasive. Basic abrasive properties are type of material, size, shape, density, hardness, and friability.

Size is tremendously important for consistent blast pattern with desired surface texture. Abrasive sizing conforms to industry standard sieve measurements and is expressed as "mesh" or "microns." No abrasive sizing is precise, but good quality manufacturing methods will furnish the great majority of particles within the designated range. For example, a 20/40 mesh (850/425 micron) abrasive will consist mostly of particles between 20 and 40 mesh (850 and 425 micron) with a trace of slightly larger and a small percentage of finer material.

Size is determined by surface finishing requirements. Larger particles yield deep profiles, which is helpful in removing multilayers of paint, heavy corrosion, or concrete splatter. Medium-sized abrasive is adequate for most blasting jobs where light rust, loose paint, or thin mill scale is present. Small particles create shallow profiles and are ideal for blasting light gauge metals, plastics, and other semidelicate surfaces.

It is common practice with reusable abrasive (e.g., steel grit, aluminum oxide) to establish a "working mix" or "operating mix" of abrasive sizes. The mix principle is critical in automotive and aircraft shot peening, and sophisticated coating applications. Working mix is an average of abrasive sizes that develop while adding new abrasive to old abrasive within the blasting system. When a system is charged with new abrasive, the surface etch is fairly consistent. As the abrasive fractures or wears down, the etch begins to diminish. If allowed to recycle continually with smaller and smaller particle sizes, surface cleaning rates decline and profiles become more shallow. To counteract this situation, predetermined amounts of fresh abrasive are periodically added to the existing supply. Accurate working mixes can be established through monitoring surface results, and desired finishes can be maintained.

Size becomes of paramount importance when accurate profiles are required. Coating manufacturers specify exact profiles for their materials, which demand strict attention to abrasive sizing to prevent too deep or too shallow surface roughness. Prior to beginning a job, it is always advisable to test blast the surface with a given mesh size and measure the profile to determine if it complies with the specification.

There is a misconception that larger abrasives will get the job done faster, but this is not always the case. Although cutting deeper, there are fewer particles to do the work, consequently, there may be some untouched surface areas left with an unacceptable finish. It is best to run a number of tests with different mesh sizes to determine complete coverage with the required profile and degree of cleanliness.

Abrasive shapes impart various types of surface topography. Round articles leave a dimpled effect, and angular particles produce sharply defined valley and peak patterns. Some round abrasives are not perfect spheres, they are oblong. Angular abrasives have a variety of configurations, some being more angular than others.

Application requirements dictate which shape is the most productive. Angular abrasive is best for heavy layers of paint and corrosion. Round abrasive works well on mill scale and light contamination, and is necessary for shot peening and other stress-relieving applications.

Density, or mass, is the weight of abrasive within a given dimension. On the high side, steel grit weighs about 250 lb/ft^3 (3.8 kg/L); on the low side, walnut shell weighs only 44 lb/ft^3 (0.7 kg/L). Abrasive density is of a lesser consideration than the other properties, but increases in importance when both ends of the spectrum are compared.

Hardness is the toughness or durability of an abrasive. Most abrasive hardness is measured on the Mohs scale (steel abrasive excluded). The old Mohs scale ranked hardness from 1 to 10 with 1 being compared to talc, a soft mineral, and 10 being diamond. A newer, revised Mohs scale ranges from 1 to 15 with diamond being number 15 with more advanced manufactured materials, such as boron carbide, silicon carbide, and fused aluminum, filling in the 10 to 15 rankings. Steel abrasive hardness is measured on the Rockwell "C" scale (designated by "R_c"). Commonly used steel abrasives range from soft R_c 40 to hard R_c 66.

Logically, harder abrasives perform better on difficult cleaning jobs, whereas soft abrasive is more suitable for delicate blasting. Generally, garnet has a hardness of 7 to 8 and aluminum oxide is 9. On the soft end, agricultural abrasives are around 3 and plastic media ranges from 3 to 4.

Friability refers to the breakdown factor of abrasive, which determines the number of reuses. Friability is a result of the product's composition, hardness, and brittleness. Generally, most manufactured and byproduct abrasives have some reuse advantages. Some natural abrasives, such a garnet and flint, can be recycled, but silica sand absolutely can never be reused. Silica sand has an extremely high friability rating due to its quartz composition. It can only be used once because it pulverizes by 70 to 80% at 100 psi (690 kPa) on the first cycle. Recycling silica sand simply is not a good practice, especially in light of the increased health hazards from microscopic dust particles. Highly durable steel grit may be effectively recycled as many as 200 times. It is difficult to list reuse numbers for each abrasive because there are several variables, such as air pressure and surface hardness, that affect breakdown. Check with abrasive suppliers for accurate reuse factors.

Common Abrasive Categories

Abrasive is classified in three major categories—natural, byproduct, and manufactured. Each of these categories is discussed below.

Natural abrasive is material that was created by Mother Earth. In this category are silica sand, mineral sand, flint, garnet, zircon, and similar local mineral products. All of these abrasives have good cutting qualities and are relatively economical to use. With the exception of garnet, these abrasives are not recommended for use in an enclosed blasting system due to their rapid breakdown and, on some materials, their high composition of hazardous silica.

Garnet is an extremely hard and sharp blasting media found in specific deposits. It is well suited for tough cleaning applications that require removal of heavy surface materials and high profile texturing. Physical characteristics allow limited reuse advantages. Bulk density of garnet is around 140 lb/ft^3 (2.1 kg/L).

The byproduct abrasive classification includes agricultural products, which are disposable materials generated from another process, but prove to be highly effective as blast cleaning agents.

There are several types of agricultural media on the market. Two of the most popular are walnut shell and corncob. Agricultural media, which are lightweight [40+ lb/ft^3 (0.6 kg/L)] and soft (Mohs scale of 3), are suitable for applications where paint and other substances are to be removed without affecting the underlying surface. Used properly, their soft, resilient composition will not etch metal or other hard surfaces. As an example, these media are utilized extensively on electric motor cleaning where damage to stator lamination and wire insulation is to be avoided. Other common operations are paint stripping of wood, plastics, and light gauge metals.

The manufactured abrasive category has a variety of metal and nonmetal compositions, and physical features. Typically, metal abrasives are steel and iron; nonmetals are aluminum oxide, silicon carbide, plastic, wheat starch, and glass bead. Although there is some overlap in applications, each type of manufactured abrasive plays a specialized role.

Abrasive Descriptions

Due to precise surface finishing requirements in the automotive and aircraft industries, metal abrasive development and utilization has become a controlled science. Primary usage for metal abrasive was only in airless centrifugal wheel blast machines where a bombardment with a high volume of cleaning particles on steel substrate required heavy, long-lasting blasting media. Recent advancements in abrasive recovery and cleaning systems have greatly increased the scope of applications where a metal abrasive can be used for environmentally acceptable, economical, high-production air blast applications.

There are three main metal abrasive types—steel, malleable iron, and chilled cast iron. Each type is manufactured in two shapes—round shot and angular grit. Of the three types, steel is by far the most widely used abrasive because of its unexcelled reuse factor. There are claims of steel being recycled 200 times and more. Chilled cast iron may be reused about 50 to 100 times and malleable iron slightly longer than chilled iron. Economies of recycling clearly favor steel abrasive, but selection of the type of metal abrasive is predicated on several application factors.

Steel hardness ranges from 35 to 65 R_c; malleable iron from 28 to 40 R_c; and chilled iron from 57 to 68 R_c. As with all other abrasives, surface condition and desired finish determine the hardness necessary to do the work.

Chilled iron and malleable iron are less expensive than steel and are used where blasting installations experience a heavy loss of abrasive in the process of loading and unloading parts. Additionally, iron is more brittle and tends to break down into angular particles, making it more aggressive than steel.

Steel particles deform on impact rather than shatter, like iron, into smaller pieces. Steel abrasive actually wears away until the particles become too small to be usable. Due to the long life of steel, new abrasive must be continually added to maintain a consistent blast pattern. Larger particles impact the surface with more kinetic force than small particles; therefore, it is necessary to establish an operating mix and monitor the amount of small, medium, and large particles to ensure that the desired surface finish does not change.

Metal abrasive sizing is standardized to the Society of Automotive Engineers (SAE) specifications. Grit sizes are designated G-10 (2.0/1.7 mm) to G-120 (0.125/0.075 mm), with G-10 being the largest. Shot sizes range from S-70 (0.125/0.180 mm) to S-780 (1.7/2.0 mm), with S-780 being the largest size. Grit is semiangular and provides valley and peak profiles. Shot, being round, produces a dimpled effect on a surface, often referred to as "shot peening."

Shot peening is a carefully controlled process where parts subject to stress fatigue can be strengthened by peening. The impact of round pellets at high velocity imparts a compressed layer over the surface. The compression layer actually diffuses stress forces across a larger area of the part, resulting in a stronger, longer-life part. Shot peening is a vital process in many industries, such as automotive, aircraft, and gears. Shot is also widely used for cleaning castings and forgings, and in many airless blast machines to remove mill scale from new steel plate, pipe, and other steel substrate.

Silicon carbide is the hardest, sharpest, most expensive abrasive on the market. It is used for unique applications where optimum abrasion is required. These media measure 9 on the Mohs scale (original) and are close to the hardness of diamond. One primary use of this abrasive is removing heat-treat residue from hardened parts. There are various special surface finish applications where a fine but deep cutting abrasive is necessary.

Aluminum oxide, which rates second only to silicon carbide in sharpness, is the popular choice for super tough cleaning jobs. Its cost dictates that these media be utilized in enclosed blasting systems that recover and filter abrasive. With a density of 120 lb/ft^3 (1.8 kg/L) and hardness of 8 on the original Mohs scale, aluminum oxide is the most aggressive, high-volume abrasive in the blasting industry.

There are several purity grades available to accommodate specifications that require minimal amounts of contamination Aerospace and aircraft industries use aluminum oxide for cleaning and deburring on titanium, magnesium, and other sophisticated metals where ferrous contamination must be prevented. Standard grades are used on aluminum, brass, iron, and steel castings to remove flashing quickly while cleaning the surface. Often, other abrasives are mixed with aluminum oxide to obtain blended matte finishes with deep cleaning action.

Aluminum oxide is offered in a wide range of sizes from fine to extra coarse. It can be recycled several times depending on whether it is used in suction- or pressure-blast systems. Users will experience accelerated wear on equipment components that come in contact with the media at high velocity. When blasting with aluminum oxide, nozzles lined with boron carbide are recommended to extend nozzle wear life. Interior rubber lining on blasting enclosures is also encouraged.

Glass bead is a unique abrasive media developed to remove surface contaminants without affecting dimensional tolerances; to provide a polished finish; and, in some cases, to shot peen for stress relief. Glass bead is manufactured from lead-free, soda-lime-type glass and contains no free silica. Its shape is almost perfectly spherical, making it ideal media for

Table V. Abrasive Comparison Chart

Material	Mesh Size	Shape	Density, lb/ft^3	Mohs	Friability	Init. Cost	No. of Cycles	Per Use Cost	Source
Silica sand	6-270	■•	100	5.0–6.0	High	Low	1	Med.	Nat.
Mineral slag	8-80	■	85–112	7.0–7.5	High	Med.	1–2	Med.	Bp
Steel grit	10-325	■	230	8.0	Low	High	200+	Med.	Mfg.
Steel shot	8-200	•	280	8.0	Low	High	200+	Low	Mfg.
Aluminum oxide	12-325	■	125	8.0–9.0+	Med.	High	6–8	Med.	Mfg.
Glass bead	10-400	•	85–90	5.5	Med.	Med.	8–10	Low	Mfg.
Plastic	12-80	■	45–60	3.0–4.0	Low/Med.	High	8–10	Med.	Mfg.
Wheat starch	12-50	■	90	2.8–3.0	High	High	10–12	High	Bp
Corn cob	8-40	■	35–45	2.0–4.5	Med.	Low	4–5	Low	Bp

■, angular; •, spherical; Nat., natural; Bp, byproduct; Mfg., manufactured.

shot peening uniformity. Its relative hardness of Mohs scale 6 and glass composition cause a high degree of friability; however, using lower nozzle air pressures will prolong the useful life of the media. Typically, air pressure settings for glass bead in suction systems are 70–80 psi (483–552 kPa), and 40–60 psi (276–414 kPa) in pressure systems. Excessive pressures destroy glass bead prematurely and do not increase productivity to any reasonable extent.

Glass bead sizes range from U.S. standard mesh screen 12/14 (1.68/1.41 mm) to 170/325 (0.088/0.044 mm) (U.S. Federal Specifications MIL-G9954A: Size 1 to Size 13). Identical surface finish can be consistently accomplished by maintaining an operating mix of bead sizes. As bead breaks down, new bead must be added based on a predetermined blast cycle.

There are countless uses for glass bead. Chief industries are automotive, aircraft, and die casting where it is critical to maintain dimensional integrity of the pieces being processed. Glass bead's high purity prevents contamination on stainless steel, aluminum, and other soft metal materials. It is especially effective in deburring, deflashing, heat-treat scale removal, blending of tooling marks, and producing an aesthetic appearance on all types of metal. Shot peening with glass bead is an excellent method to reduce crack corrosion failure and provides tension relief on products that are subject to high operational stress.

Crushed plastic and wheat starch are newer blasting media on the market. They are gaining popularity in applications where paint and corrosive material must be removed without disturbing the base substrate. Being angular and resilient, they have proven to be effective in removing unwanted substance from light gauge metal and high-tech composite material without causing damage. The advent of these media has opened up a market that previously would never have been considered in the abrasive blasting process.

Potential uses of plastic and wheat starch can be found in paint stripping of many light gauge metals, fiberglass, various advanced composite materials, and even some wood products. These media are widely used on trucks, buses, automobiles, planes, and boats. They are also used in the electronics industry for flashing removal from sensitive circuitry parts. Due to their ability to remove only surface materials, they are ideal for mold cleaning and precision electronic deburring.

A comparison chart of different media is shown in Table V.

Further information on the application of plastic and other media for paint stripping can be found elsewhere in this *Guidebook*.