OSEA2010
The 18th International Oil & Gas Industry Exhibition & Conference
SINCE 1976

Bristle-blast Surface Preparation Process for Reduced Environmental Contamination and Improved Health/Safety Management[1]

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ABSTRACT

Maintenance of both on-shore and off-shore petroleum installations is a key concern throughout the oil and gas industry. In particular, engineers must continuously monitor corrosion and establish a schedule for periodic maintenance of all physical systems that are prone to corrosion. To this end, the grit blast cleaning process is routinely used for corrosion removal and surface preparation, thereby providing an anchor profile for subsequently applied paints and coatings. However, grit blast cleaning processes are cumbersome and inevitably require special equipment, containment systems, and subsequent clean-up due to the widespread contamination that is inherent of the process. Consequently, there is a strong need to develop alternative surface preparation processes that forego the expense and environmental setbacks that are commonly associated with existing grit blast cleaning operations.

In this technical paper, several key surface preparation processes are reviewed that can *simultaneously* remove corrosion and generate a requisite surface profile. Included among these processes is the recently developed method termed *bristle blasting*, which is capable of generating cleaned, textured surfaces that are equivalent to commercial grit blasting processes. This newly developed process, however, does not require the use of complex equipment, containment, or the retrieval of spent media. It is demonstrated that the bristle blast cleaning process can reduce/eliminate environmental contamination, and can minimize the risk of health or safety hazards to the user or to those working in the nearby vicinity. In addition, this paper reviews the physical principles upon which the function of the tool is based, and results are presented for corrosion removal applications involving API 5L steel, which is commonly used in the petroleum industry. These results demonstrate that bristle blast technology produces surfaces having a cleanliness and texture quality that is ordinarily associated with traditional grit blast cleaning processes, namely, SP-10 (near-white metal blast cleaning) and SP-5 (white metal blast cleaning).

INTRODUCTION AND BACKGROUND

The physical infrastructure of both on-shore and off-shore oil and gas facilities relies upon properly functioning structural components for successful daily operation. Platforms, piping, and connectors, for example, are key elements that provide a framework for extracting, controlling and transporting the liquids and gases that are central to this industries mission. Consequently, facilities maintenance is an important component of the overall effort and cost that is necessary to ensure uninterrupted and efficient operation. A significant portion of this effort involves the periodic evaluation and scheduled maintenance of any component whose deterioration and eventual failure can jeopardize the steady flow of product. To this end, maintenance engineers are responsible for ensuring that the integrity of all components is upheld and, in particular, that the damaging effects of corrosion are treated by using the

[1] Submitted for presentation at the 18th International Oil and Gas Industry and Conference, OSEA, Singapore, November 30-December 3, 2010.

most advanced surface preparation and coating technologies. At the same time, national and federal regulations are requiring that less toxic, “green” technologies be developed and used in order to reduce the environmental impact that discharged surface cleaning media and coating debris can have on the ecosystem.

Likewise, the personnel that are responsible for maintaining this infrastructure are a key asset for ensuring daily successful operation of the facility. Both their skill sets and health/safety concerns are of paramount importance for establishing a reliable, efficient operation. Deliberate measures must be taken to minimize/eliminate the counterproductive costs associated with worker fatigue, injury, and sickness. Once again, maintenance engineers must understand any risks that are associated with implementing tools/technologies that are used for preparing surfaces as well as the toxic hazards that are associated with the application of paints and coatings. The working environment must be regularly monitored in order to detect and avert hazardous conditions that can affect air quality, noise, vibration, and other factors that can undermine worker safety. Equally important, action must be taken in order to ensure that safe conditions and minimal risk are present.

Aspects of pipeline maintenance: Surface treatment processes

Protective coatings eventually deteriorate and expose base metal to a corrosive environment. If unchecked, corrosion can readily advance to a critical stage that will undermine the integrity of pipeline installations, thereby halting recovery and transport operations. Pipeline maintenance and restoration is, therefore, an essential part of daily operations for oil and gas industries, and specialized personnel and equipment are devoted to the task of evaluating the severity of corrosion and performing in-field repairs. Typically, this involves the use of specially designed tools that are capable of simultaneously performing several tasks that are essential to the repair process, namely;

(1) removing both the corrosive layers and previously applied coatings that no longer provide adequate protection against further damage,
(2) exposing a base metal that is visually clean/contamination-free, and
(3) generating a receptive surface profile that will accommodate/promote adhesive bonding of the subsequently applied coating.

To this end, several surface preparation processes have emerged that are capable of meeting all three of the above requirements in a single cleaning operation. Most notably, the following generic surface cleaning methods have risen to the forefront:

- Grit blasting
- Needle gun
- Rotary cutter bundles
- Rotary flap[2]
- Wire bristle impact[3]

Each of the above cleaning processes involves the use of both special equipment and skill-sets, and each approach carries with it advantages, limitations, and specific risks and hazards that are inherent to the process. Regrettably, little information can be found in the engineering literature that compares and contrasts each of the above surface preparation processes, especially in connection with their

[2] Commercial trade name Rotopeen
[3] Commercial trade name Bristle blaster

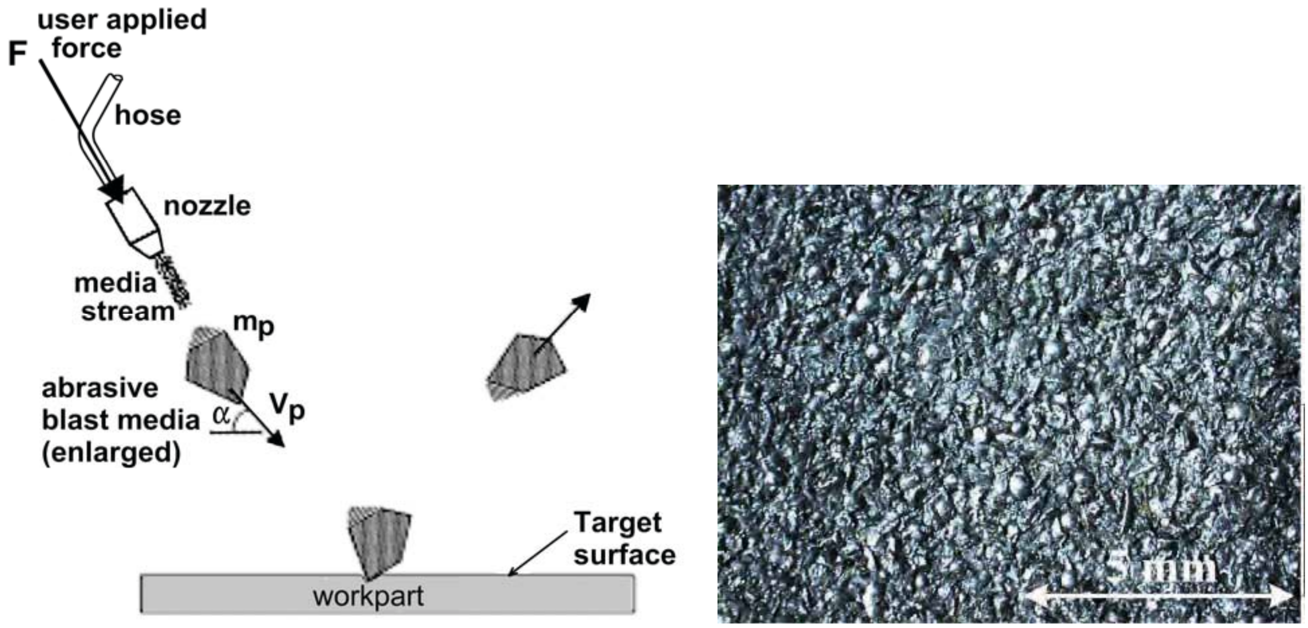
documented performance, range of application, and ecological and personal risks/hazards. Therefore, the remainder of this section is aimed at examining several of these concerns and providing information that can be useful to maintenance engineers that are charged with selecting appropriate surface preparation tools and processes.

Grit blasting process

Grit blasting is the most widely used method for surface preparation, and involves the application of a high-speed stream of granular media (steel, coal slag, etc.) onto a target surface, as shown in Figure 1a. The material removal performance and efficiency of grit blasting is primarily based upon the kinetic energy or *available energy* that is stored in the particle stream and is given by [1]

$$e_p = \tfrac{1}{2}\, m_p v_p^2 \sin^2 \alpha \quad , \tag{1}$$

where m_p and v_p are the mass and incoming speed of grit particles, respectively, and α is the orientation angle of the nozzle/particle stream relative to the target surface. Thus, for a nozzle angle that is greater



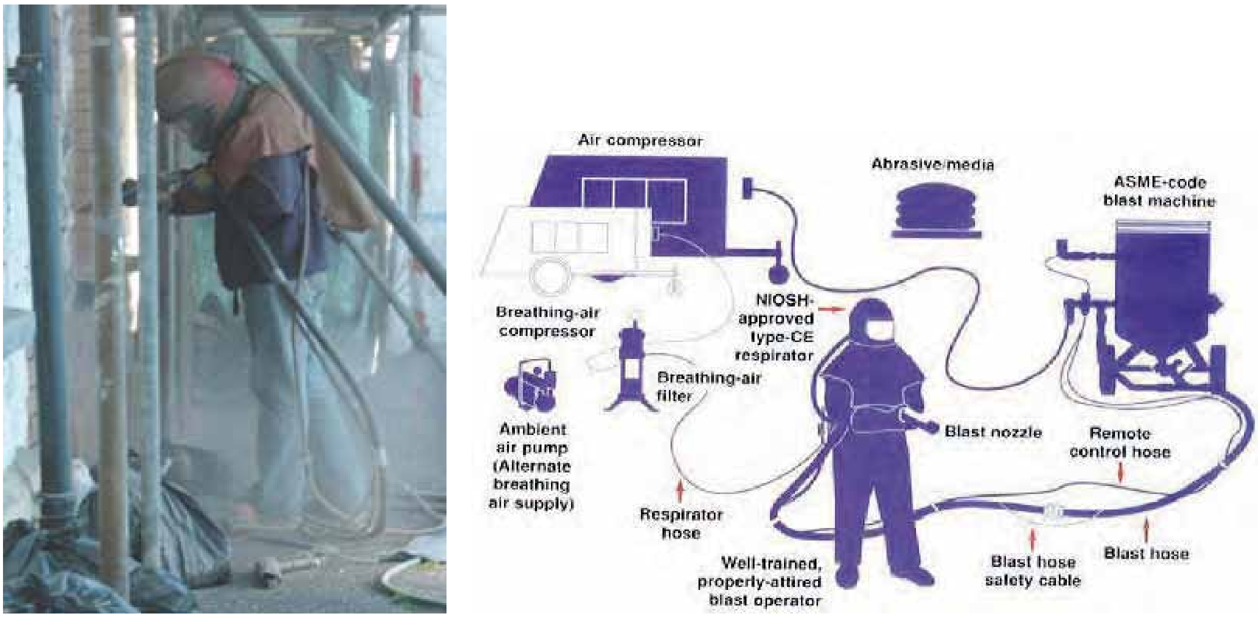
(a) (b)

Figure 1 (a) Schematic of abrasive blasting process, and (b) characteristic grit blast surface generated by G16 steel media.

than 75 degrees, $\sin^2 \alpha \approx 1$, and both the kinetic energy and performance of the process is skewed toward the speed of grit particles. Although common grit speeds cited in the literature typically range from 50 to 130 m/s, significantly greater speeds can be realized by appropriate nozzle design in conjunction with an elevated pressure supply system. Repeated impact of media with the workpart surface results in crater-like formations shown in Figure 1b, whose coarseness/texture is largely determined by the size and shape of the media [2, 3]. Overall, grit blasting is the most versatile mechanical cleaning process, and can offer the broadest range of cleaning thoroughness and texture refinement.

As shown in Figure 2a, the grit blasting process can produce hazardous dust and debris and, therefore, must be performed by an individual that is confined or encapsulated in a control-suit, which both filters dust and supplies fresh air from a remote source. Furthermore, the noise level emitted by such equipment varies from 112 to 119 dBA [4], which is well above the OSHA threshold level of 85 dBA whereby employer action is advised for both the user and those working in the nearby area [4].

The equipment/apparatus that is used for carrying out grit blast operations is shown in Figure 2b, and indicates that the process is complex, costly, and requires considerable set-up time. Prior to performing the surface preparation process, preliminary results must be obtained which ensure that both efficient



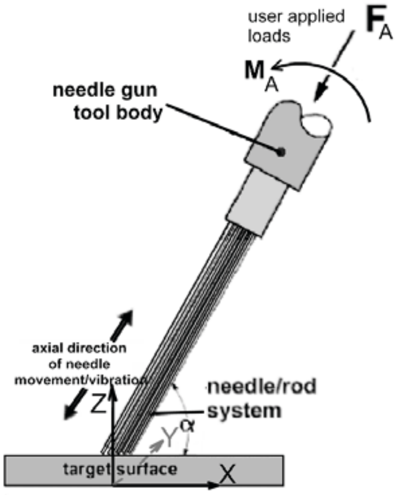
(a) **(b)**

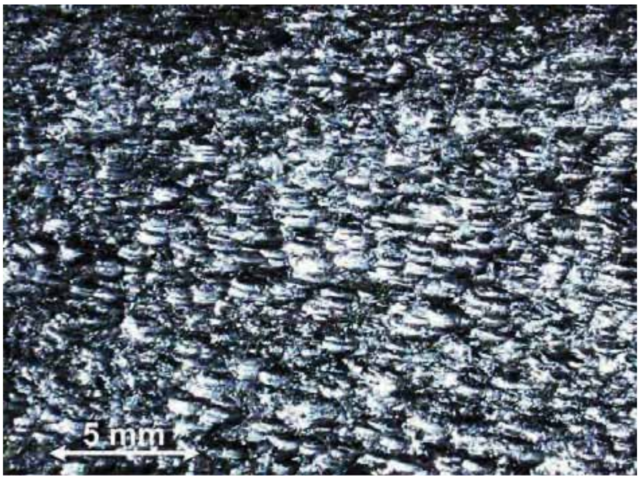
Figure 2 (a) Grit blast working environment/application, and (b) typical equipment/apparatus required for carrying out grit blast process.

and safe operating conditions have been achieved. This is inevitably accompanied by the use of sampling/monitoring devices that measure and confirm that proper function and suitable air quality has been obtained. Throughout the cleaning process, the temperature within the encapsulation suit can rise to uncomfortable levels, and a steady operating reaction force (see Figure 1a) of approximately 88 N (20 lb) (excluding the nozzle and hose weight) must often be applied/sustained by the worker [5]. Upon completion, shut-down and equipment clean-up is necessary, and the spent media must be retrieved and contained for subsequent proper disposal. Altogether, these requirements render the abrasive blasting process especially inefficient and poorly suited for applications involving local rehabilitation or "spot-repair", wherein steel surfaces are in need of immediate repair due to paint delamination and/or severe corrosion.

<u>*Needle gun cleaning process*</u>

The needle gun is a percussive power hand-tool that involves the use of small diameter, rapidly vibrating rods that oscillate over a prescribed range of frequencies (typically 2,700 to 4,500 strikes per minute). Noise levels cited in the product literature for this tool typically varies from 98 to 109 dBA , which is also above the previously cited OSHA action threshold of 85 dBA.   As shown in Figure 3a, the



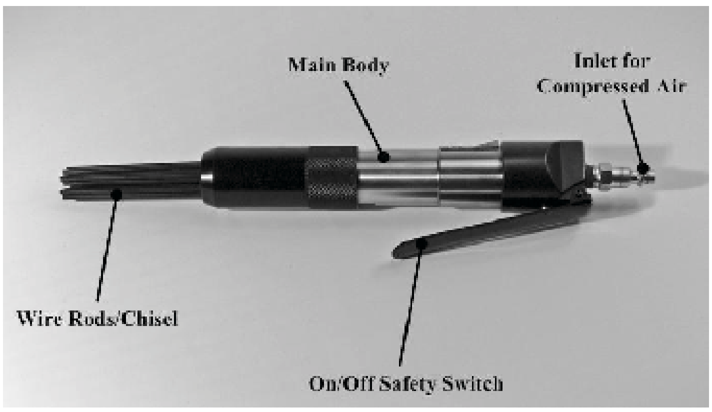


(a) **(b)**

Figure 3 (a) Schematic of needle gun depicting user-applied force F_A and moment M_A, tool orientation angle α, and axial mode of vibratory oscillating rods, and (b) typical surface texture generated by repetitious contact of rod tips with target surface. Elliptic micro-indentations are indicative of corner contact made between wire rods and target surface.

tool is directed along the target surface at an angle of inclination α, while a sustained force F_A and moment M_A are applied to the tool by the user. Consequently, contact of rod tips with the target surface removes debris and generates the elliptically-shaped indentation pattern shown in Figure 3b. This tool is most adept at cleaning and preparing surfaces that have experienced severe corrosion, deeply pitted corrosion, and for circumstances wherein the advanced stages of corrosion have led to a multilayered /fragmented corrosive surface. However, little information has been reported in the engineering literature regarding the performance of needle gun tools, or the capacity that these tools have for generating surfaces that satisfy both cleanliness and texture standards. Therefore, the performance, capability, and range of application of this tool remain largely uncertain.

As shown in Figure 4, the pneumatic needle gun (Figure 4a) is operated by grasping the body of the tool with both hands, and directly exerting the wire rod tips against the contaminated surface (see Figure 4b). This direct coupling of the user/tool and workpart surface generates a vibratory force that



(a) **(b)**

Figure 4 (a) Needle gun used for collecting data reported in Figure 5, and (b) common needle gun cleaning application/environment.

characterizes the needle gun cleaning process. Recently, laboratory measurements were made in order to investigate the magnitude of force that is generated during a standard cleaning application and therefore, the (equal and opposite) forces exerted by the operator/hand-tool system [6]. These results, which exclude the weight of the needle gun (15 N [3.5 lb]) are shown in Figure 5 for three different levels of exertion, namely, low (left), medium (center), and high (right). The force components F_x, F_y, and F_z correspond to the coordinate system illustrated in Figure 3a, and indicate that significant

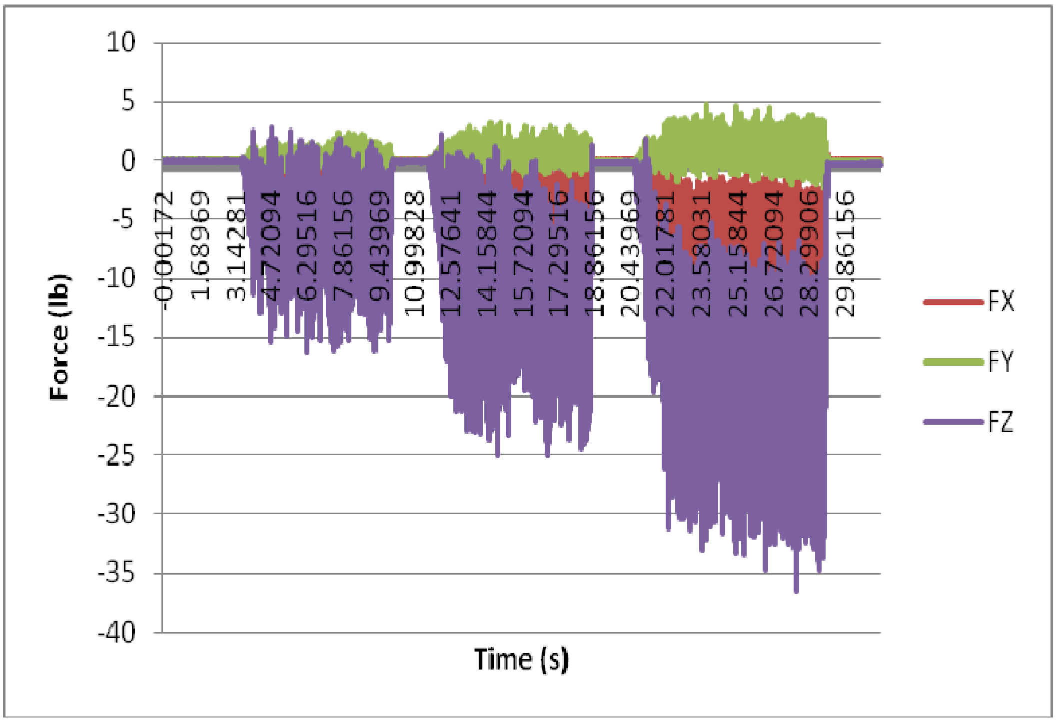
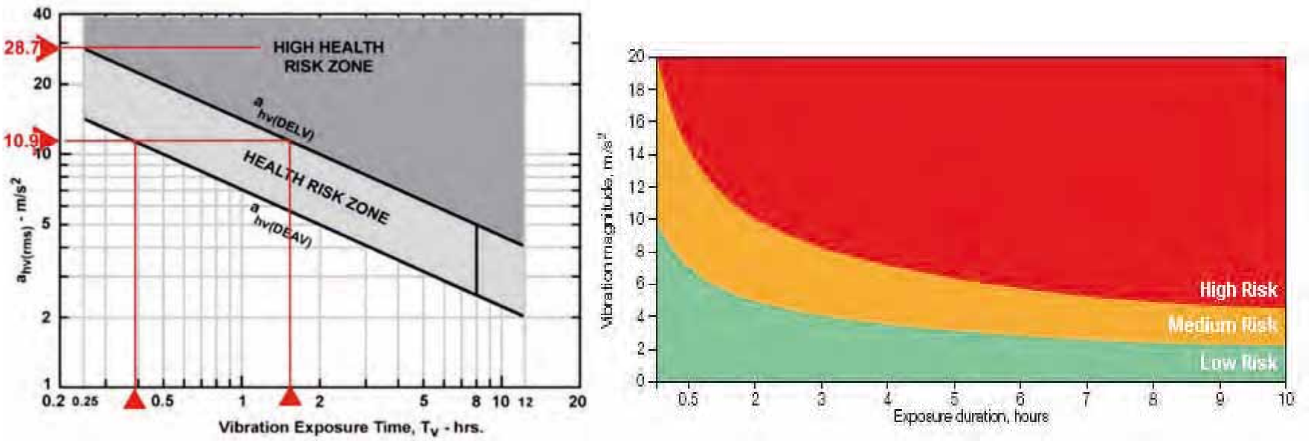


Figure 5 Measured vibratory force generated by needle gun when exerted against vertical steel surface during typical surface cleaning exercise. Three different levels of force exertion, namely, low (left), medium (center), and high (right) were used during the cleaning operation [6]. (API 5L steel, air supply pressure 100 psi, angle of inclination α ≈ 60 degrees). Results exclude the weight of the needle gun (15 N [3.5 lb]).

vibratory force is transmitted to the user. Specifically, the (approximate) mean force exerted by the user is 30 N (7 lb), 53 N (12 lb), and 75 N (17 lb) for the low, medium, and high force exertion, respectively. In general, these results are well below the user reaction force that was previously cited for the grit blast process.

The reaction forces shown in Figure 5 must be supplemented by additional information regarding the magnitude of the vibratory *acceleration* imparted by the needle gun tool to the user. This information is of vital importance because it is recognized that daily exposure of power hand-tool acceleration to the user can lead to serious, long-term personal injury. Such health disorders have been termed Hand-arm Vibration Syndrome (HAVS), and Injuries that can arise from needle gun usage have been the subject of considerable investigation [7-12]. Research has established that the severity of HAVS injuries is closely related to both the magnitude of the acceleration of the power tool, and the time duration that one is exposed to the acceleration. Thus, norms/standards have been developed that help quantify the risk that one may face as a consequence of power tool-induced vibration. Two widely published standards (see Refs. [8] and [10], for example) are shown in Figures 6a (ANSI, U.S.A.) and 6b (HSE, U.K.). Use of this information is straightforward, and requires that the level/severity of acceleration associated with a particular power hand-tool (vertical axis) be determined. Based upon this level of tool acceleration, the charts can then be used to obtain the associated risk that workers face when the tool is used daily for a specific hourly period (horizontal axis). As a means of illustration, for example, measurements have shown [7, 8] that the typical acceleration issued from needle guns ranges from 10.9 to 28.7 m/s^2. This



(a) **(b)**

Figure 6 Standard/norms published by (a) ANSI, (U.S.A.) and (b) HSE, (U.K.) indicating the relationship between the magnitude of tool vibratory acceleration (vertical axis) and worker exposure hours (horizontal axis) that can lead to worker risk for HAVS injury. Results shown in Figure 6(a) are for needle gun power tools (data obtained from Refs. [7, 8]).

information is used in Figure 6a (see red horizontal lines) to obtain the corresponding health risk of needle gun tools, and indicates that the onset of health risk for 10.9 m/s^2 is less than ½ hour of daily exposure, whereas the onset of high risk begins at less than 2 hours of daily use. The (red) horizontal line drawn at 28.7 m/s^2, however, indicates that the user is subject to high health risk for any duration of exposure. The reader may verify by direct use of Figure 6b that both US and UK standards are in close agreement regarding the threshold magnitude of acceleration that can lead to health risks associated with HAVS.

The serious health concerns associated with HAVS has led to the development of *attenuation* or *anti-vibration gloves* (AVG), which are specifically designed to reduce tool acceleration levels. Thus, the use of AVG devices can allow workers to use the tool for a longer duration, while minimizing personal risk. However, earlier research reported in the literature [11] concluded that anti-vibration gloves offer little, if any, benefit to the user. More recently [12], it has been reported that the effectiveness of AVG products is still of dubious value, because ongoing tests have revealed that they do not satisfy ISO/ANSI criteria.

Rotary cutter bundles and rotary flap tool processes

Rotary cutter bundles and rotary flap tools are jointly reviewed in this section due to their similarity in function and design. As shown in Figure 7, both varieties of tools have a clustered arrangement of cutters or flaps that are spindle-driven at approximately 2,500 rpm. The clusters are comprised of markedly different media, however, which accounts for the unique performance that is offered by these tools. Therefore, details concerning the composition and fabrication that are peculiar to each of these tools/media are briefly reviewed in this section.

The typical design of a cutter bundle tool is shown in Figure 7a, and consists of 6 rows or clusters of hardened steel spurs/stars, each supported by a pin/shaft connection that allows the cluster to rotate/reposition freely. The tips of each spur form the working edges of the tool, which randomly impact the target surface as the central hub of the tool rotates. Upon impact, spur tips strike the surface, thereby removing debris and exposing base metal. At the same time, textural features that are characteristic of star tips are imparted to the workpart, which generates the desired surface profile. Material removal performance of the tool is largely attributed to the kinetic energy of the system, which is derived from the mass and velocity of the rotary spur discs.

(a) **(b)**

Figure 7 (a) Typical cutter bundle surface preparation tool comprised of 6 rows of spur-like hardened steel discs, and (b) rotary flap surface preparation tool consisting of 6 equally spaced rows of multi-faceted tungsten carbide shot.

Similarly, the rotary flap tool shown in Figure 7b consists of 6 rows/clusters of flaps, each having multi-faceted tungsten carbide shot that is brazed to a steel rivet. The steel rivet, in turn, is attached to a compliant flap, which serves as a delivery vehicle for the tungsten carbide/rivet system. During impact, the mass of the tungsten carbide shot is significantly enhanced by the steel rivet/flap assembly. Thus, the enhanced mass of the system in conjunction with the rotational speed of the assembly, provide the kinetic energy for impact and tool performance. At the same time, textural features are imparted to the surface that is characteristic of the multi-faceted tungsten carbide shot.

Little or no information has been reported in the engineering literature regarding the noise levels, user-applied loads, or the vibratory accelerations that are generated when cutter bundles or rotary flap tools are used for surface preparation processes. Moreover, neither the material removal performance nor the quantitative capacity that these tools have for generating cleaned, profiled surfaces can be found. Therefore, the performance, capability, and personal risks of injury associated with use of these tools remain largely uncertain.

<u>*Wire bristle impact process*</u>

The wire bristle impact or *bristle blasting* process is a recent innovation for surface preparation that utilizes a rotary wire disk which operates at a spindle speed of approximately 2,500 rpm. Noise level s emitted by this equipment are reportedly the same (approximately 83.5 dBA) for both the pneumatic and electric versions of this power tool [15], which is somewhat below the previously cited OSHA action level of 85 dBA. The basic principle of operation for this tool is depicted in Figure 8a for a single wire bristle that is attached to a rotating hub, whereby counterclockwise rotation of the tool results in contact of the bristle tip with the accelerator bar. This collision results in the (rearward) retraction of the bristle which, in turn, stores additional energy within the bristle. Upon release from the accelerator bar, the bristle accelerates forward, and strikes the workpart surface at the impact site as shown. Upon impact, the bristle tip forms a crater-like micro-indentation [13], and subsequently retracts from the surface. This process is repeated as each bristle passes through the contact zone, and leads to the

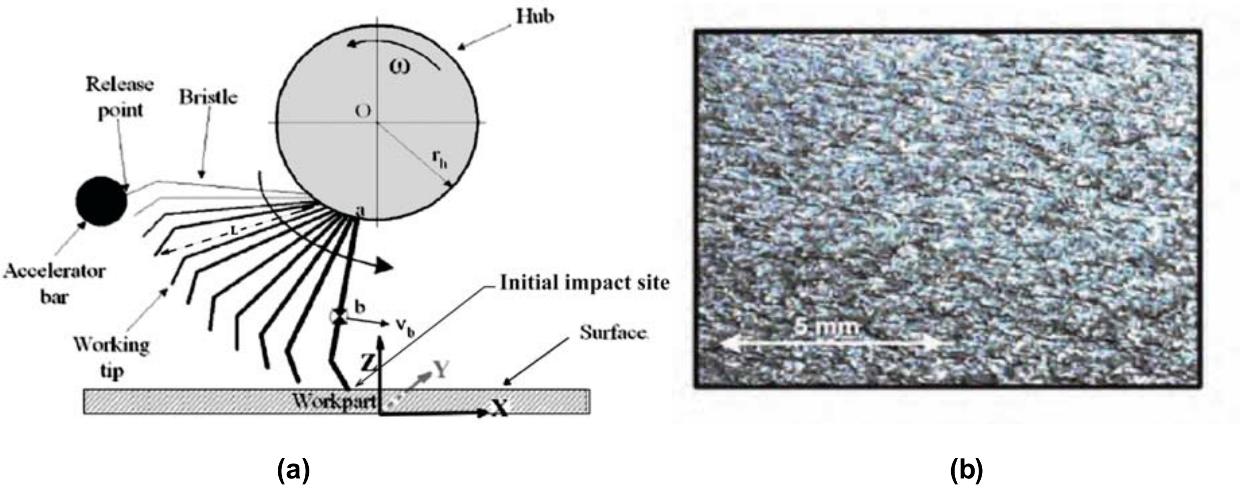


Figure 8   (a) Schematic of single wire bristle motion during bristle blasting process, and (b) characteristic surface generated by bristle blaster.

characteristic surface shown in Figure 8b. Performance of the tool is closely related to the kinetic energy of the bristle itself, which is given by:

$$e_b = \frac{1}{2} m_b v_G^2 + \frac{1}{2} I_G \omega^2 \qquad (2)$$

where v_G is the speed of the bristle mass center, I_G is the mass moment of inertia of the bristle about the mass center, and ω is the angular velocity of the spindle, which is directly related to the spindle speed n (rpm) via the relation $\omega = n\pi/30$. A rational comparison can now be made between the kinetic energy of blast media e_p (reference Equation (1)) and the corresponding kinetic energy of a rotating bristle e_b given by Equation (2). Thus, direct equality of the two different media energies and algebraic rearrangement yields

$$n = \frac{30 v_p}{\pi} \left[\sqrt{\frac{m_b}{m_p} \frac{\frac{1}{12} L^2 + (\frac{L}{2} + r_h)^2}{\sin^2 \alpha}} \right]^{-1} \qquad (3)$$

where L is the nominal bristle length, and r_h is the radius of the bristle tool hub (reference Figure 8). Equation (3) forms a basis for comparing the “equivalent” energy content of the two different surface cleaning processes.   Thus, the usefulness of Equation (3) is shown in Figure 9 for a range of standard steel media mesh sizes (G10, G12, … , G25) and nozzle orientation angle α = 70 degrees, in conjunction with the dimensions of a commercially available bristle blasting tool [14] shown in Figure 10a. As a

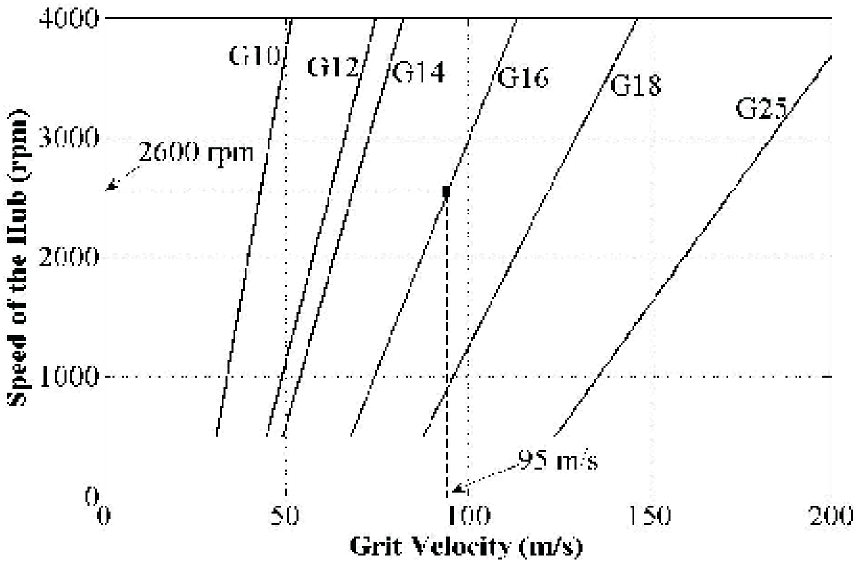
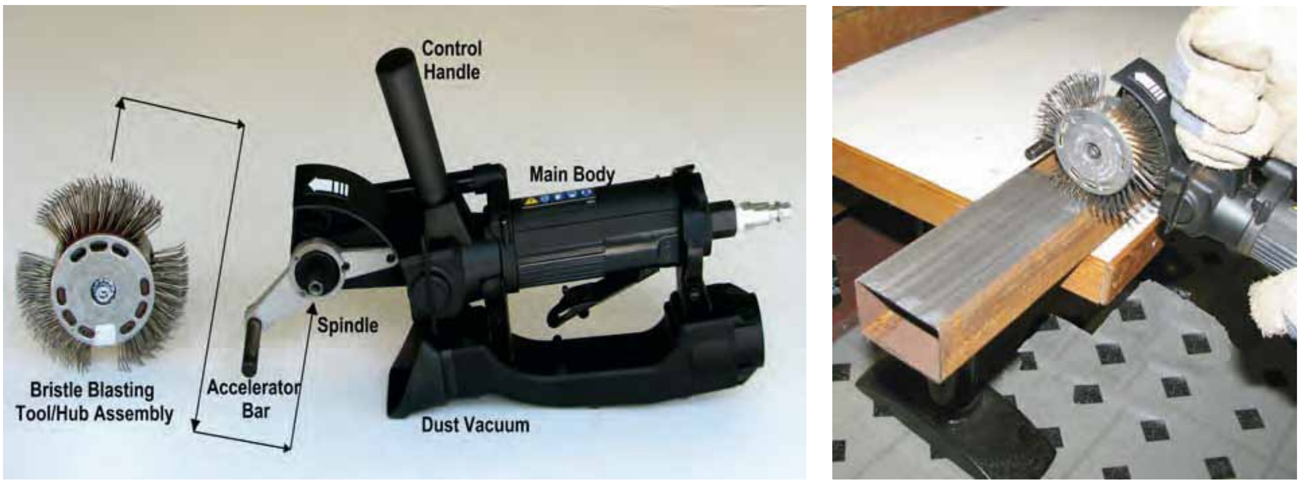


Figure 9 Relationship between bristle blaster spindle speed and grit velocity for various steel media sizes [14]. (Note: spindle speed 2600 rpm corresponds to grit velocity of 95 m/s for G16 steel media)

practical illustration, for example, the use of G16 steel media (diameter ≈ 1mm) having a nozzle exit speed of 95 m/s corresponds to the bristle blasting tool operating at the spindle speed n = 2,600 rpm.



(a) **(b)**

Figure 10 (a) Components of a bristle blaster power tool (pneumatic version shown), and (b) common bristle blast cleaning application.

As shown in Figure 10a and 10b, the bristle blast power tool is operated by grasping both the control handle and the main body of the tool (Figure 10a), and directly exerting the working surface of the tool against the contaminated surface (Figure 10b). As previously discussed, direct coupling of the user/tool and workpart surface generates a vibratory force that characterizes the cleaning process. In this case, the vibratory force components F_x, F_y, and F_z [ref. Figure 8a] associated with bristle blasting tools are reported in Figure 11 for two different levels of force exerted by the operator [14]. The first plateau corresponds to the ordinary use of the tool, and results in a mean operating force of approximately 13 N (3 lb), whereas the second plateau corresponds to heavy penetration of the tool, and results in a

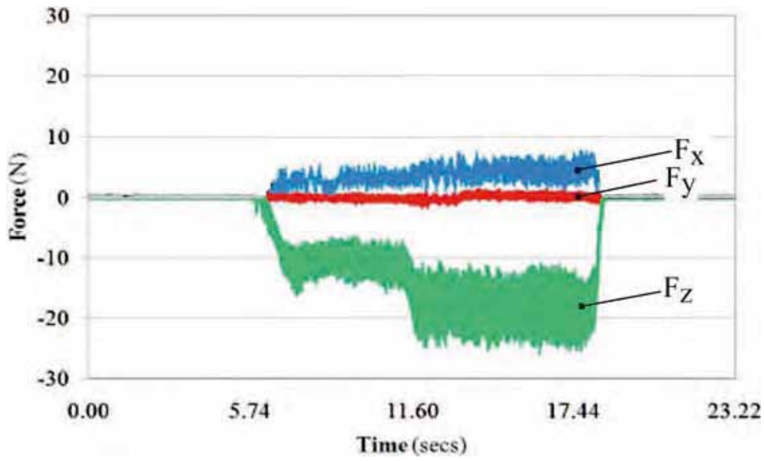


Figure 11 Measured vibratory force generated by bristle blasting tool when exerted against vertical steel surface during typical surface cleaning exercise. Two different levels of force exertion, namely, normal (first plateau) and heavy (second plateau) were used during the cleaning operation [14]. (API 5L steel, results exclude the weight of the bristle blasting tool (10 N [2.4 lb]).

mean operating force of approximately 20 N (4.5 lb). These results, which exclude the weight of the bristle blasting tool (10 N [2.4lb]), are well below the user-applied force for grit blasting operations, and are considerably less than those reported for the needle gun (ref. Figure 5).

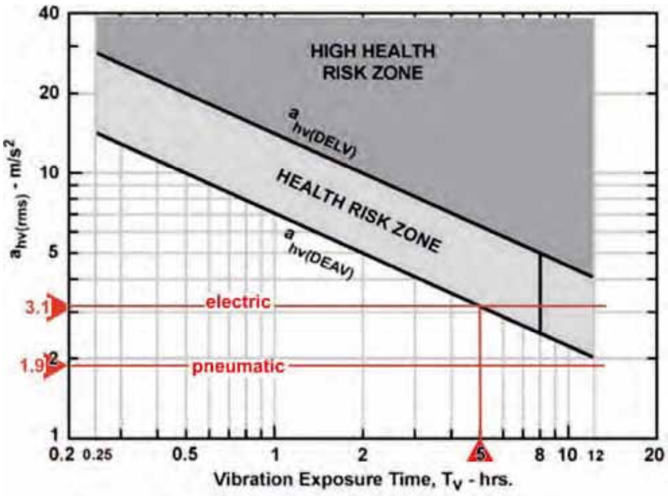


Figure 12 Standard/norms published by ANSI, (U.S.A.), and comparative results for two versions (electric and pneumatic) of the commercially available bristle blasting tool. Results shown for bristle blaster were obtained from Ref. [15].

Information regarding the vibratory acceleration of the tool is shown in Figure 12, whereby (red) horizontal lines correspond to the measured accelerations reported in ref. [15] for both the electric and pneumatic version of the bristle blaster. These results indicate that the electric power tool issues an acceleration of 3.1 m/s^2, and can be used for up to 5 hours before the onset of health risk; continued use of the tool beyond this period, however, enters the health risk zone. Finally, the vibratory acceleration associated with the pneumatic power tool is 1.9 m/s^2 and, as shown in Figure 12, does not pose a health risk to the user for any period of use published by ANSI.

PERFORMANCE OF BRISTLE BLAST SURFACE PREPARATION PROCESSES

Bristle blasting is yet a recently developed surface preparation process, and limited information can be found in the engineering literature regarding proper guidelines for tool use. Therefore, this section begins with a tutorial review of the step-wise procedure that currently represents the best practice/procedure for implementing the bristle blasting process.

Standard Recommended Procedure for Tool Use[16, 17, 18]

All manual surface treatment processes require dexterity, visual acuity, and a basic understanding of key parameters that affect the performance of surface finishing equipment. Training and experience are, therefore, important factors that enable users to develop skills that are needed for a successful outcome. The skill-sets that are essential for successful application of the bristle blasting process are quite similar to those needed for other surface treatment processes, and include the following:

1) proper orientation of the tool in relation to the target surface,
2) control of tool force exerted onto the surface, and
3) the feed rate and direction of the tool during operation.

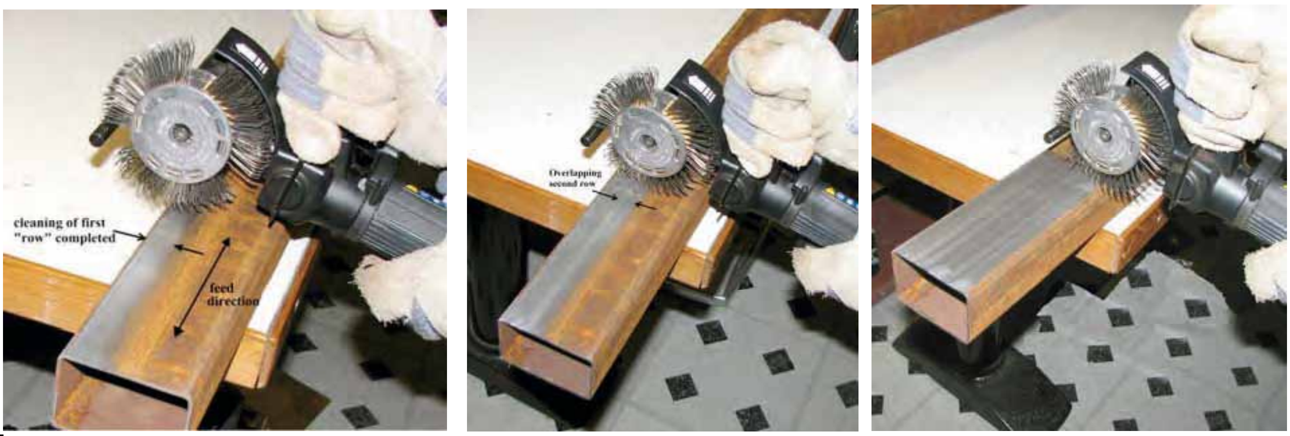
In the following discussion, each of these user-based considerations is briefly discussed within the context of a common corrosion removal application.

<u>Initializing the process cleaning parameters</u>

Appropriate selection of the bristle blasting process parameters can be readily established by first, identifying a candidate surface that requires cleaning, and isolating a portion of the surface for initial cleaning/testing. In general, the face of the tool hub is oriented perpendicular to the treated surface during use, as shown in Fig. 13. During corrosion removal, the bristle tips are brought into direct contact with the corroded surface using minimal applied force, and the rotating tool is gradually moved along the feed direction, that is, either to the left or right of the user (see Fig. 13a). Thus, the appropriate pressure and feed rate of the tool is obtained by direct experimentation and by visually inspecting the trial-tested region to ensure that the desired cleaning standard/requirement is reached.

<u>Method/pattern for continuous systematic cleaning</u>

Having obtained the appropriate process parameters for corrosion removal, the user then identifies the region to be treated, and develops a simple plan for obtaining complete coverage. As shown in Fig. 13a, for example, the surface of a corroded steel component must be cleaned. The user, in turn, has elected to begin the corrosion removal process at the extreme left end of the component, and has applied the working surface of the tool along the feed direction, i.e., from left to right. This procedure has resulted in a cleaned and textured horizontal *band* or *row*, which appears in Fig. 13a. Equally important, the user has started the cleaning operation along the top (uppermost) portion of the corroded surface, and will perform all subsequent cleaning by the use of overlapping bands that have their starting point *below* (under) the previously cleaned region. That is, correct use and *optimal cleaning/texturing performance* of the tool requires that each overlapping successive band is generated *beneath* the previously cleaned region/row. Therefore, as shown in Fig.13b, the user has correctly overlapped the previously cleaned region, and has generated/cleaned the next row by placing the working surface of the rotating tool directly below the initially prepared surface.



(a) **(b)** **(c)**

Figure 13 Recommended use of bristle blasting tool for corrosion removal. First, a horizontal row is prepared (Fig. 13(a)) using minimal applied force and steady feed rate. The process is then repeated by overlapping the second row (Fig. 13(b)) with the previous row that was cleaned. Finally, the entire surface is cleaned (Fig. 13(c)) by repeatedly overlapping each row with the previously cleaned region until full coverage is completed.

Completing the corrosion removal process

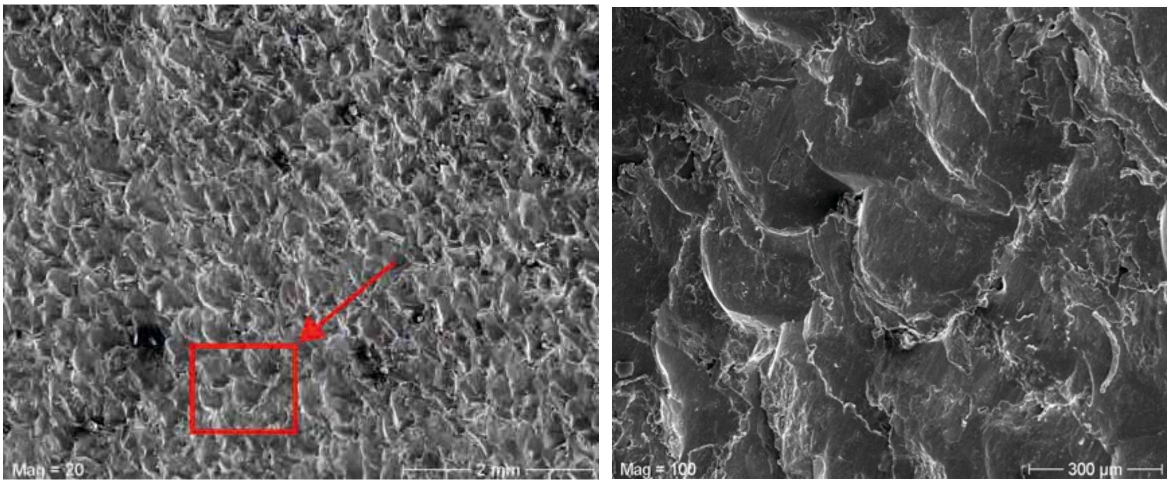
Corroded components can be completely cleaned by repeating the previously described procedure. Thus, as shown in Fig. 13c, the top surface of the corroded beam has been completely cleaned, and the user is ready to remove corrosion from any remaining surfaces. Finally, if any portion of the surface is identified where unsatisfactory cleaning has been obtained, the user can return to these locations for final “touch-up” cleaning, as needed.

Case Study of Bristle Blasting Tool Application

Generally, all material surface preparation tools and processes generate markings on the target surface that uniquely characterize the process itself. For example, careful examination of the surfaces shown in Figures 1b (grit blast), 3b (needle gun), and 8b (bristle blast) show distinctive micro-indentation patterns that reveal a particular mode of mechanical interaction between the media and the metallic surface. This observation is equally valid for the surfaces generated by previously discussed cutter bundle and rotary flap tools as well. However, limited information is available regarding the technical function of these tools and, therefore, details remain unavailable. In this section, the characteristic surfaces generated by the bristle blasting process, as well as the cleanliness, texture, and material removal capacity of the tool is briefly reviewed.

Morphology of bristle blast surface

Although the photograph shown in Figure 8b depicts a coarse, cleaned surface, further details concerning the interaction between the bristle tip/workpart surface must be obtained at higher magnification. In Figure 14a the surface is viewed at higher magnification (20X), whereby the repetitious contact of bristle tips can be readily identified. Further enlargement of the indicated region (see arrow) is shown in Figure 14b (100X), and reveals the formation of individual adjacent craters that are generated during impact. Such craters have been the subject of previous research [1, 14], which concluded that these “shoveling” micro-indentations are analogous to those generated during grit blasting processes[13].



(a) **(b)**

Figure 14 (a) Scanning electron micrograph of typical bristle blast surface (20x), and (b) higher resolution scanning electron micrograph (100x) of region indicted by arrow in Fig.(a).

<u>Cleanliness of bristle blast surface</u>

In Figure 15, a section of API 5L piping is shown, which is widely used for on-shore/off-shore applications in the petroleum industry. The as-received/initial condition of the pipe exhibits uniform, severe corrosion along the interior and exterior of the pipe. Further examination of the surface (see

Figure 15 Section of 150mm [6 in] diameter corroded API 5L pipe used for evaluating performance of bristle blasting tool.

Figure 15, inset) suggests that *SSPC Condition D* (100% rust with pits) characterizes the severity of this stage of corrosion. This section of corroded pipe is used for assessing the cleaning performance of bristle blasting processes and the result is shown in Figure 16 before corrosion removal (bottom) and after corrosion removal (top)[13]. One may observe that the cleaned surface is free of corrosion along the surface as well as within pits, and that the surface condition meets cleanliness standard SP-5 (white metal).

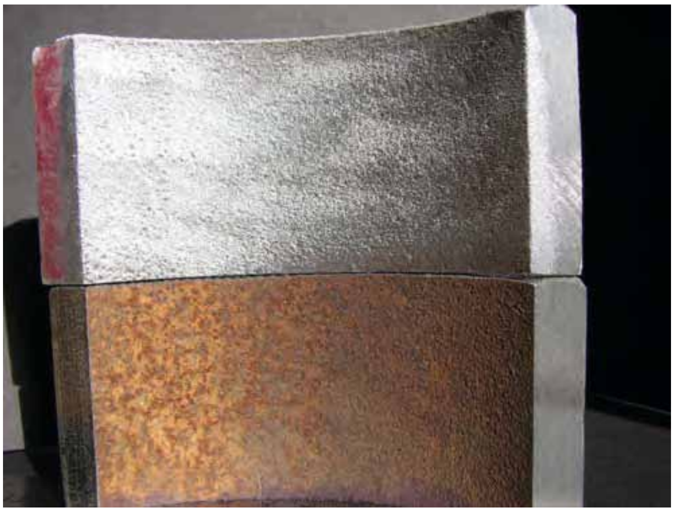


Figure 16   Interior of API 5L piping in as-received condition (bottom), and after bristle blast cleaning (top).

Texture/profile of bristle blast surface

Finally, the texture/profile of cleaned surfaces shown in Figure 16 is measured and reported in Figure 17. These data were obtained using standard press-film replica tape, and include the gradual wear of the bristle blasting tool over a 70 minute period of continuous use[13]. The results show that surface texture regularly declines as the duty cycle of the tool increases, which is attributed to the progressive

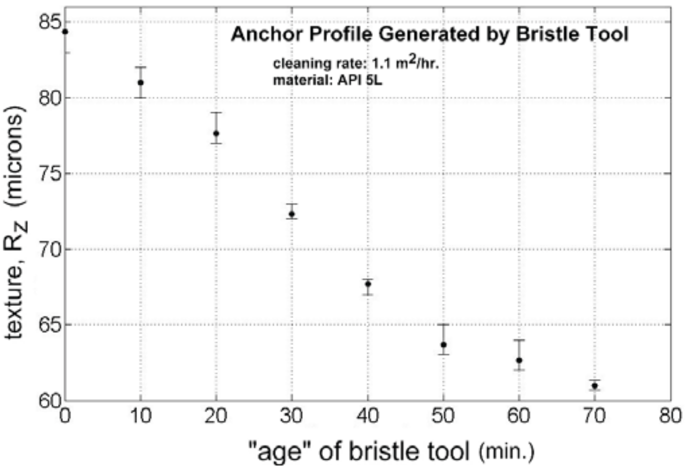


Figure 17   Variation of surface texture/anchor profile as bristle tool progressively ages. Approximate bristle tool specifications: face width: 22 mm, hub radius: 29 mm, bristle wire diameter: 0.73 mm, bristle length: 29 mm, total bristle population ~480.

wear of bristle tips during service[16]. Throughout the period of use, an anchor profile is generated that varies from R_Z = 84 microns for an as-received (i.e., new) tool, to R_Z = 62 microns at the conclusion of the tools life.

Summary and Conclusion

Five (5) surface preparation processes have been identified and discussed that can simultaneously satisfy 3 important functional requirements, namely:

•perform thorough removal of surface contamination,
•expose base metal, and
•develop an adequate surface profile for subsequently applied paints and coatings.
These processes are of considerable interest to the surface finishing community due to their inherent simplicity and cost-saving capability. To this end, the environmental/health-related concerns of these processes have been briefly reviewed, and the findings are summarized in Table 1.

	Type of Surface Preparation Process					
Health Concern	**Grit Blast**	**Needle Gun**	**Cutter Bundle**	**Rotary Flap**	**Bristle Blast**	
					Pneumatic	Electric
Noise level[4] dBA	112 to 119	98 to 109[5]	UNKNOWN	UNKNOWN	83.5	83.5
Vibration Level m/s^2	Non-vibratory	10.9 to 28.7	UNKNOWN	UNKNOWN	1.9	3.1
HAVS declaration (ANSI-U.S.A.)	Not applicable	**HEALTH RISK** 0.4 hrs. to 1.5 hrs. of use @10.9	**HEALTH RISK** UNKNOWN	**HEALTH RISK** UNKNOWN	**HEALTH RISK** none	**HEALTH RISK** After 5.0 hrs. of use
	Not applicable	**HIGH HEALTH RISK** Always present @28.7	**HIGH HEALTH RISK** UNKNOWN	**HIGH HEALTH RISK** UNKNOWN	**HIGH HEALTH RISK** none	**HIGH HEALTH RISK** none
Fatigue User-applied force Newton (LB)	88 (20)	30 (7) to 75 (17)	UNKNOWN	UNKNOWN	13 (3) to 20 (4.5)	13 (3) to 20 (4.5)

Table 1 Summary of findings/health concerns for 5 different surface preparation processes.

First and perhaps foremost, the results shown in Table 1 point to an urgent need for independent research and disclosure of the user risks associated with cutter bundle and rotary flap surface preparation tools. In particular, the absence of noise and vibration data places undue liability on the employer and great uncertainty on the safety of workers that perform surface preparation tasks. At the same time, uncertainty surrounds the effectiveness of AVG devices due to their lack of compliance with ISO/ANSI criteria. This, in turn, casts doubt on the safety of workers that make use of special protective equipment.

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[4] OSHA employer action threshold: 85 dBA.
OSHA Personal Exposure Limit (PEL): 90dBA (protective equipment required)
[5] Based upon product literature; does not constitute independently reported finding.

Finally, a relatively new surface preparation technology termed *bristle blasting* has been briefly introduced, along with the physical principles of operation that characterize the process. A cursory review of the information given in Table 1 indicates that this approach appears to have least impact on worker health and safety concerns. That is, the noise, vibration (barring grit blast processes), and worker-applied force associated with carrying out bristle blasting is apparently least detrimental to personal health and safety issues. At the same time, the effectiveness of the bristle blasting process has been examined within the context of cleaning severely corroded surfaces comprised of API 5L steel piping, which is commonly used in the petroleum industries. These results have shown that SP-5 (white-metal) cleanliness can be readily obtained, and that tool life can meet or exceed 1 hour of continuous service life.

Acknowledgement

The author gratefully acknowledges the assistance of Professor Raymond A. Fournelle and Mr. Piyush Khullar, whose efforts helped provide some of the information reported in the *Case Studies* portion of this paper.

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