Paper No.
10385

NACE INTERNATIONAL
CORROSION 2010
CONFERENCE & EXPO

SURFACE PREPARATION OF SHIP-CONSTRUCTION STEEL/(ABS-A) VIA BRISTLE BLASTING PROCESS

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ABSTRACT

Bristle blasting is a new and unique corrosion removal process that is rapidly gaining widespread acceptance among engineers and practitioners in the corrosion/surface preparation community. This process involves the use of a specially designed wire bristle tool that is precisely tuned to the spindle speed of a power tool that rotates at approximately 2,500 rpm. That is, the principle of operation is based upon synchronized/repeated impact and rebound of bristle tips with a target surface, leading to a multitude of impact craters that remove corrosion, expose fresh substrate material, and generate a required anchor profile

In this paper, the cleanliness and texture of surfaces generated by the bristle blasting process is examined and reported. Specifically, the present work is aimed at evaluating the cleanliness, surface profile, and material removal performance that can be achieved for steel (ABS-A) that is commonly used in ship building industries. In addition, results are reported that assess the relationship between tool longevity and surface texture performance, which can form a basis for estimating the overall life expectancy of the bristle blasting tool.

Finally, basic issues concerning the recommended norms for using the bristle blaster are briefly introduced, and a comparison of surfaces generated by the bristle blasting process is made with those generated by other conventional surface finishing tools and processes. Based upon this comparison, the morphology of surfaces generated by bristle blasting is shown to be similar to those generated by grit blasting technology.

KEY WORDS

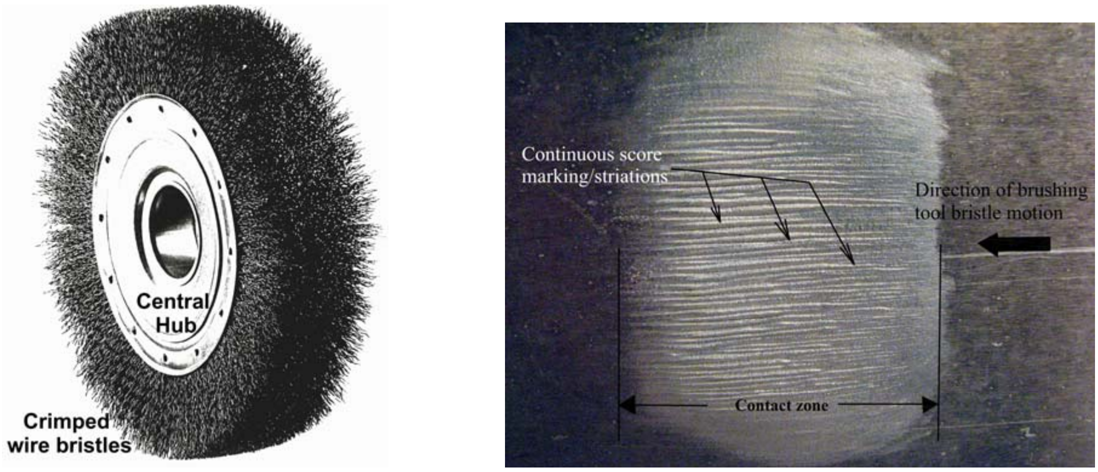
Anchor Profile; Bristle Blasting; Corrosion Removal; Surface Cleaning Processes; Surface Preparation Processes.

REVIEW OF MECHANICAL SURFACE CLEANING TECHNOLOGIES

Several mechanical technologies/processes that are currently used for cleaning and texturing metallic surfaces are briefly reviewed in this section. The relative newness of the bristle blasting process however, warrants a more detailed account of the hardware, mechanics, and methodology that is peculiar to this emerging technology. Thus, synopses of several key issues that characterize bristle blasting technology have been reiterated at the conclusion of this section.

Wire Brushes

Wire brushing tools are comprised of flexible metallic bristles that are anchored to a rotating hub, as shown in Figure 1a. As the hub rotates, wire tips repeatedly contact the workpart surface and generate striations, or score markings throughout the region of contact. These striations are caused by bristle tips, which essentially plow through the contact zone, thereby generating a multitude of parallel troughs that remove both surface debris and parent material. Consequently, the textured surface consists of striations/score markings depicted in Figure 1b, which trace the path that individual bristle tips have traversed during the material removal process.

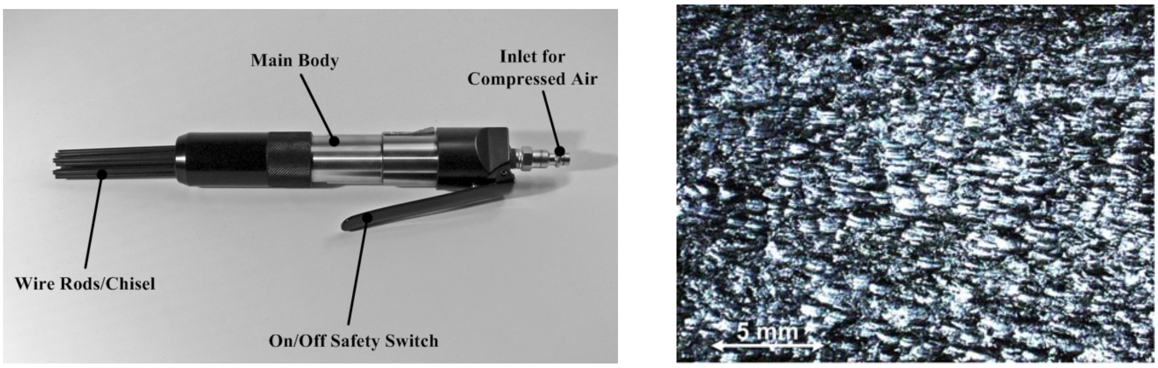


(a) (b)

Figure 1 (a) Conventional wire brush and (b) typical brushed surface illustrating continuous score markings generated throughout the contact zone.

Needle Guns

As shown in Figure 2a, the needle gun consists of a bundle of parallel wire rods or “chisels” that are placed in contact with the workpart surface. When the tool is activated, the wires rapidly oscillate back and forth (i.e., along the axial direction) thereby causing repeated contact and indentation between the wire tips and target surface. This repeated contact, in turn, leads



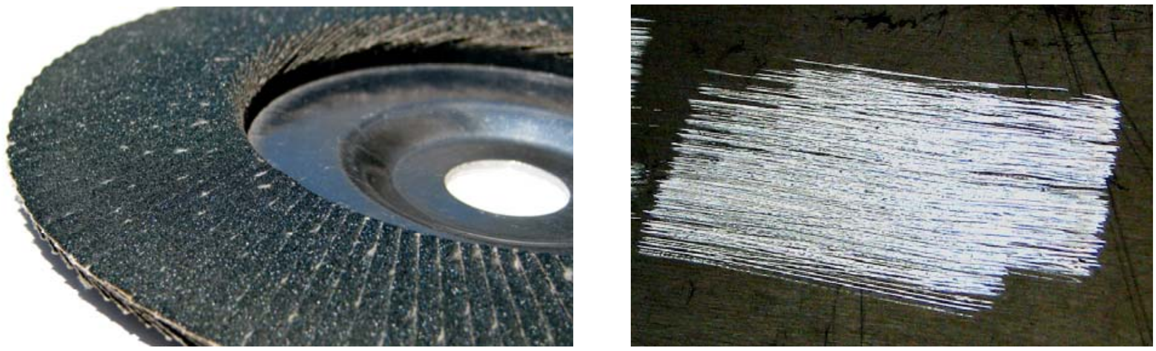
(a) **(b)**

Figure 2 (a) 12-rod pneumatic needle gun and (b) typical textured surface after corrosion removal.

to the removal of surface debris and simultaneously generates the coarsened surface texture depicted in Figure 2b.

Bonded Abrasives

The term *bonded abrasives* refers to a variety of grinding tools that use sharp granular mineral to cut through corroded surfaces. The construction/format of the tool can vary and includes a wide range of rotating/reciprocating coated abrasive pads, discs (see Figure 3a) or wheels, and non-woven abrasive pads, discs or wheels. In any case, the principle of operation is similar; that is, while force is exerted onto the abrasive-laden tool, the mineral cuts through both the surface contaminant and base metal. Consequently, the textured surface consists of striations/score markings (see Figure 3b) that trace the path of individual grains during the material removal process.



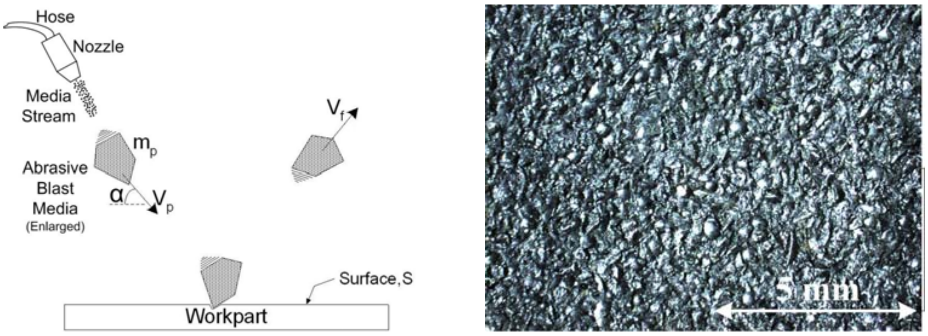
(a) **(b)**

Figure 3 (a) Power abrasive disc and (b) ground/treated surface illustrating score markings generated by cutting mineral throughout the contacting region.

The use of these tools is known to generate high temperatures within the substrate, which may or may not be accompanied by surface burn marks/discoloration. In any case, high surface temperatures are known to create conditions that can promote damage to the substrate and/or accelerated corrosion of the cleaned surface[1-3]. The application of greater force to grinding tools can be accompanied by greater surface temperature, which can promote greater damage to the substrate. Therefore, the use of excessive tool force must be avoided, even though this may increase the rate of cleaning/worker productivity. Despite widespread publicity of this important issue in the engineering community, a cursory review of SSPC/NACE surface preparation standards by one of the authors has shown an absence of instructional or cautionary information communicated to practitioners in the surface preparation community.

Grit Blasting

Grit blasting processes utilize "loose" abrasive grains, which are propelled toward the target surface, as shown in Figure 4a. Upon impact, each abrasive grain forms a "crater-like" micro-indentation, which simultaneously removes friable corrosion and exposes fresh substrate material. As depicted in Figure 4b, the repeated micro-indentations generate a surface texture that consists of "peaks and valleys", which are associated with the recurring impact and deformation of the workpart surface.

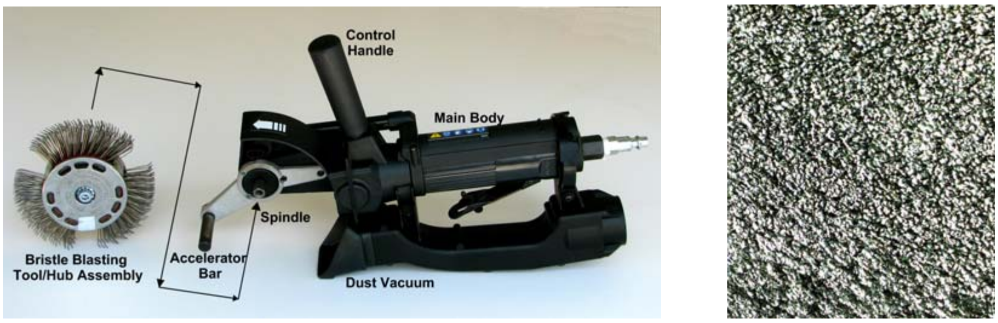


(a) **(b)**

Figure 4 (a) Schematic of abrasive blasting process, and (b) characteristic grit blast surface generated by G16 steel media.

Bristle Blasting

The recently developed bristle blasting tool (see Figure 5a) has a brush-like appearance, and consists of sparsely populated wires having sharpened tips. As the spindle rotates, each



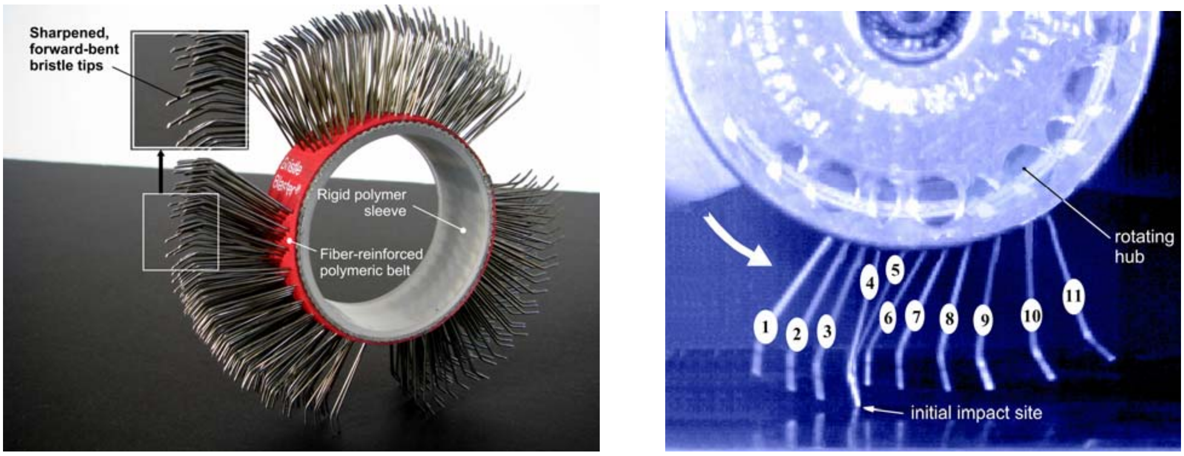
(a) **(b)**

Figure 5 (a) Recently developed bristle blasting power tool system (pneumatic version shown), and (b) characteristic surface generated by bristle blasting process.

bristle tip strikes the metallic surface and immediately retracts/rebounds, thereby causing a multitude of impact craters that are similar to those formed during grit blasting operations. This repetitious process both removes the corrosive layer and generates a fresh surface having the coarse pattern shown in Figure 5b.

Tool design and principles of operation

Details concerning the design and impact mechanics of a bristle blasting tool are shown in Figure 6, whereby sparsely populated bristles are attached/protrude through the hub or *belt* (Figure 6a), which is constructed from a flexible, high-strength, fiber-reinforced polymer that both dissipates and stores energy during the collision process. Dynamic properties of the tool are shown in Figure 6b, whereby several consecutive frames acquired by a high-speed digital camera have been superimposed for a single bristle rotating in the counterclockwise direction at 2,500 rpm. As the bristle tip approaches the workpart surface (motion is from left-to right) initial contact is made at the indicated point of impact. Upon striking the surface, a crater-like micro-indentation is formed, and the bristle tip subsequently rebounds from the surface. Throughout this duration the hub continues to rotate and the final trajectory of the bristle tip results in a single/primary impact site. Typical impact craters that are formed on a ductile steel surface are shown in Figure 7, and have been likened to *shoveling* craters that are commonly generated by grit blast media[4-6].



(a) (b)

Figure 6 (a) Design and construction of the bristle blasting tool, and (b) successive frames of a single bristle taken from high-speed digital camera depicting the approach (frames 1, 2, and 3), contact/collision (frame 4), subsequent retraction (frame 5), and return to equilibrium position (frames 6-11) of bristle

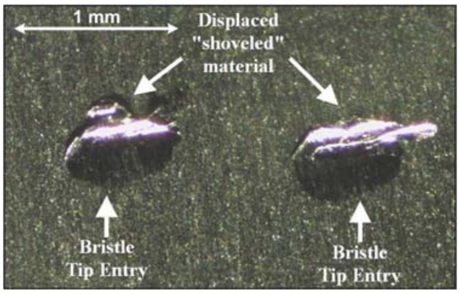


Figure 7 Typical impact craters generated by bristle blasting tool (material system: API 5L)

Kinetic energy of grit blast media vs. bristle blast wire

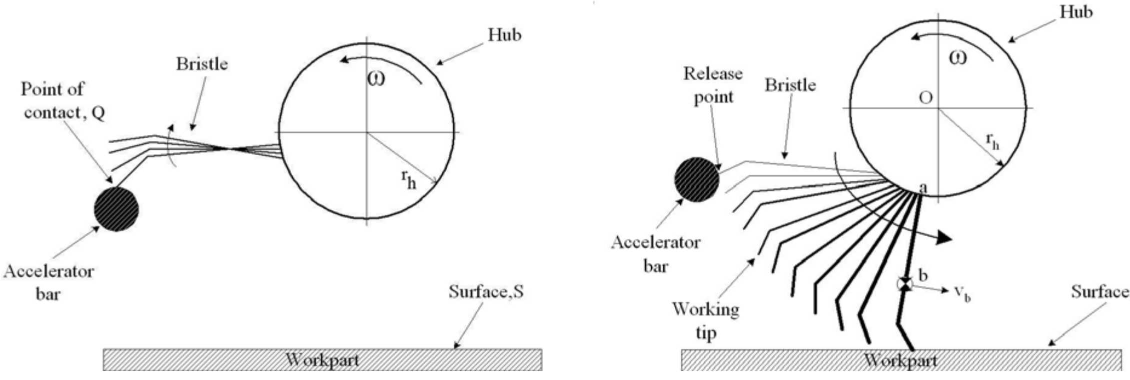
The kinetic energy content of a grit blast particle is regarded as an important measure for assessing the capacity that blast media has for both removing corrosive layers and forming micro-indentations that are needed for achieving a requisite anchor profile[7]. In this section, both the kinetic energy of a grit particle and a rotating bristle are computed; this, in turn, provides a foundation for comparing the relative performance that one may expect when using the two different processes.

A schematic representation of the grit blasting process is shown in Figure 4a and consists of a pressurized system that ejects media from a nozzle at speeds that typically range from 30-120 m/s. The kinetic energy of grit particle e_p is customarily computed[8]

$$e_p = \tfrac{1}{2} m_p v_p^2 \sin^2 \alpha \qquad (1)$$

where v_p is the speed of a grit particle having mass m_p, whose supply nozzle is inclined at an angle α relative to the horizontal target surface.

Next, an estimate for the kinetic energy of a wire bristle can be computed for a rotary tool that involves the use of an *accelerator bar*, as shown in Figure 5a. This device consists of a stationary rod that is strategically placed in the path of an oncoming, rotating bristle, and is further illustrated in Figure 8. Thus, the oncoming bristle strikes the accelerator bar and subsequently retracts (Figure 8a), thereby storing additional (potential) energy prior to being released. Upon recoil (Figure 8b), the potential energy is converted to kinetic energy and the bristle acquires additional speed prior to impact with the target surface. With the aid of a high-speed digital camera, this aspect of the problem has been recently examined by two of the present authors[9]. The results of their work (details presented in Ref. 9) are summarized below, and has shown that the following relationship between grit blast speed v_p, and spindle speed of the bristle blasting tool n(rpm) can be readily derived:



(a) **(b)**

Figure 8 (a) Depiction of bristle tips initial contact with the accelerator bar and subsequent rear-ward retraction, and (b) acceleration of bristle tip towards the target surface upon release from the accelerator bar.

$$v_p = \frac{1}{\sin \alpha} \sqrt{\frac{m_b}{m_p} \left\{ A_1 + A_2 \right\}} \qquad (2)$$

along with

$$A_1 = \left(\frac{L}{2}K + \frac{\pi}{30} n\ r_h\right)^2 \quad , \tag{2.1}$$

$$A_2 = \frac{1}{12}\left(L\,K\right)^2 \quad , \tag{2.2}$$

where m_b is the mass of the bristle, L is the nominal bristle length, r_h is the radius of the bristle tool hub (reference Figure 8b), and K = 1208.5. Equation (1) and Eqs. (2) provide a basis for comparing the *energy equivalence* of the two different processes, and the results are summarized in Figure 9. As a practical illustration, for example, the use of G16 steel media (diameter ≈ 1mm) having a nozzle exit speed of 95 m/s corresponds to bristle blasting tool operating at the spindle speed n = 2,600 rpm.

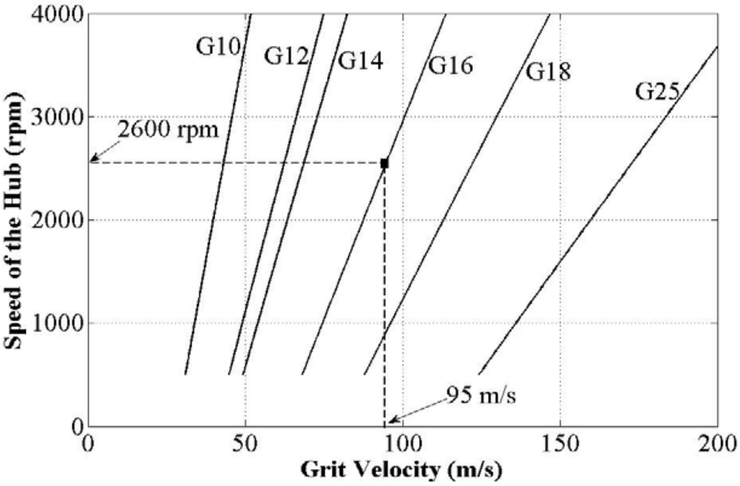


Figure 9 Relationship between spindle speed (including enhanced bristle motion) and grit velocity for various steel media. (Note: spindle speed 2600 rpm corresponds to grit velocity of 95 m/s for G16 media, and wire bristle having the following dimensional data: face width: 22 mm, hub radius: 27.5 mm, bristle wire diameter: 0.73 mm, bristle length: 27 mm, total bristle population ~480).

Implementation of bristle blasting process

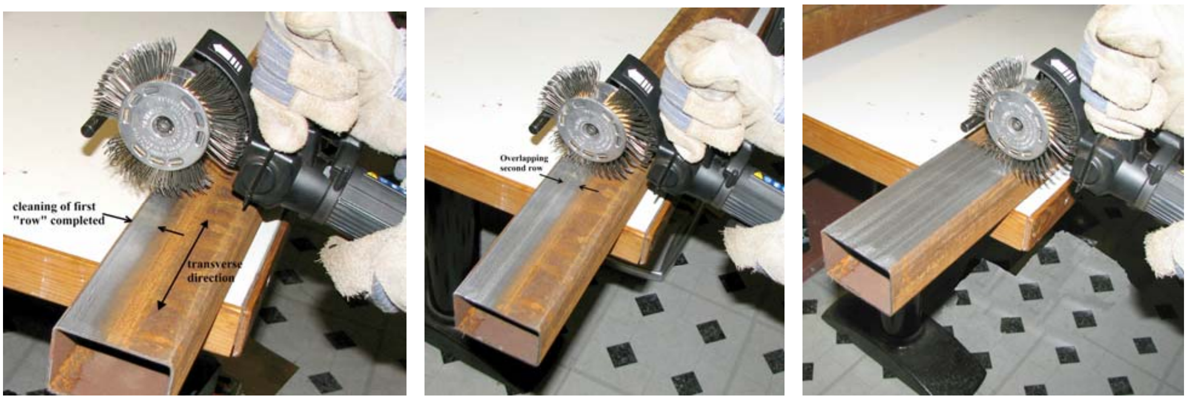
All manual surface treatment processes require dexterity, visual acuity, and a basic understanding of key parameters that affect the performance of surface finishing equipment. Training and experience are, therefore, important factors that enable users to develop skills that are needed for a successful 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.

- *Initializing the process cleaning parameters*

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. 10. 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 transverse direction, that is, either to the left or right of the user (see Fig. 10a). 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.

- *Method/pattern for continuous systematic cleaning*

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. 10a, 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 transverse direction, i.e., from left to right. This procedure has resulted in a cleaned and textured horizontal *band* or *row*, which appears in Fig. 10a. 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.10b, 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 10 Recommended use of bristle blasting tool for corrosion removal. First, a horizontal row is prepared (Fig. 10(a)) using minimal applied force and steady feed rate. The process is then repeated by overlapping the second row (Fig. 10(b)) with the previous row that was cleaned. Finally, the entire surface is cleaned (Fig. 10(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. 10c, 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.

EXPERIMENTAL EVALUATION OF BRISTLE BLASTING TOOL PERFORMANCE

Presently, there is little information available in the literature that provides a quantitative measure of bristle blasting tool performance in surface preparation applications. That is, technical information involving the performance of bristle blasting process appears to be limited to pipeline/petroleum industry applications that utilize API 5L steel, and materials of similar composition. In this investigation however, the performance of the bristle blasting process is examined within the context cleaning and profiling severely corroded ABS-A steel plate specimens, which are commonplace materials used for constructing and fabricating ships. Thus, the findings presented in this section follow a research template that has been developed for assessing the performance of bristle blasting tools in applications that are thought to be critical to the surface finishing community.

Thus, careful examination of the ABS -A specimen shown in Figure 11 indicates that the surface is comprised of a thick corrosive layer which is accompanied by significant pitting. Consequently, SSPC Condition D (100% rust with pits) appears to provide an accurate assessment of the initial severity of corrosion that has formed on the surface.

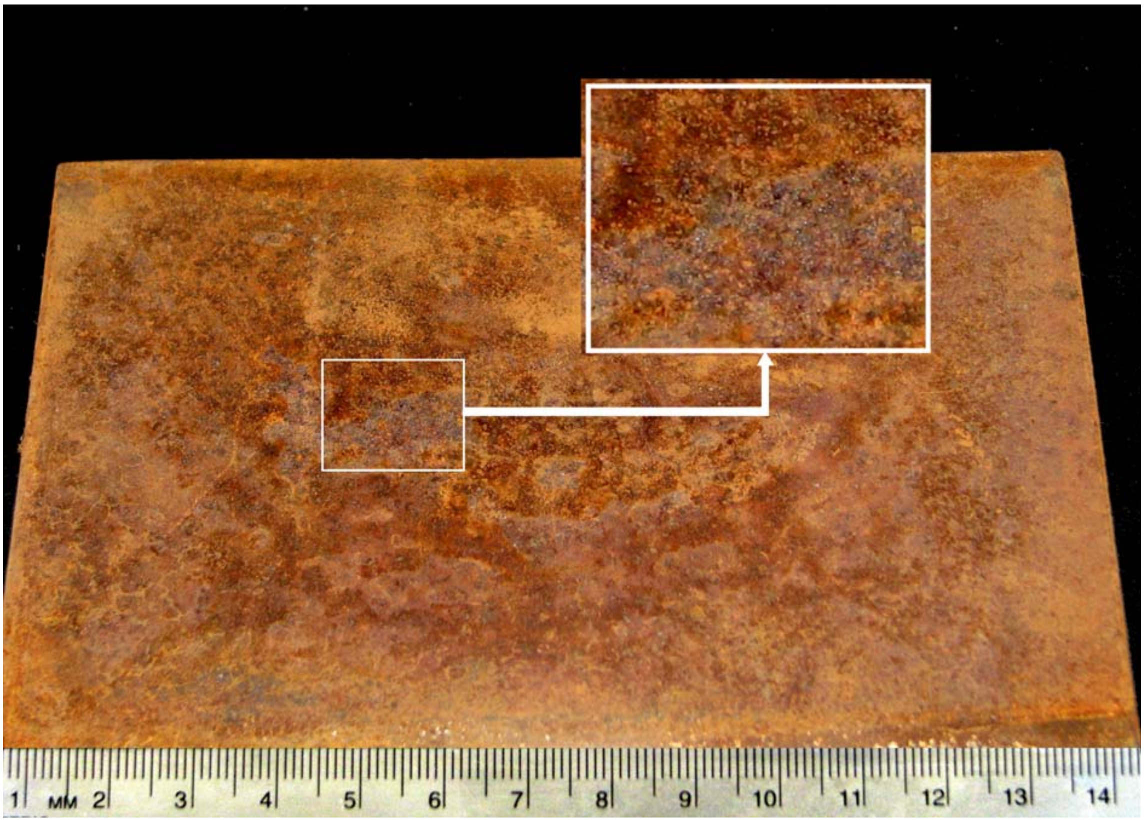
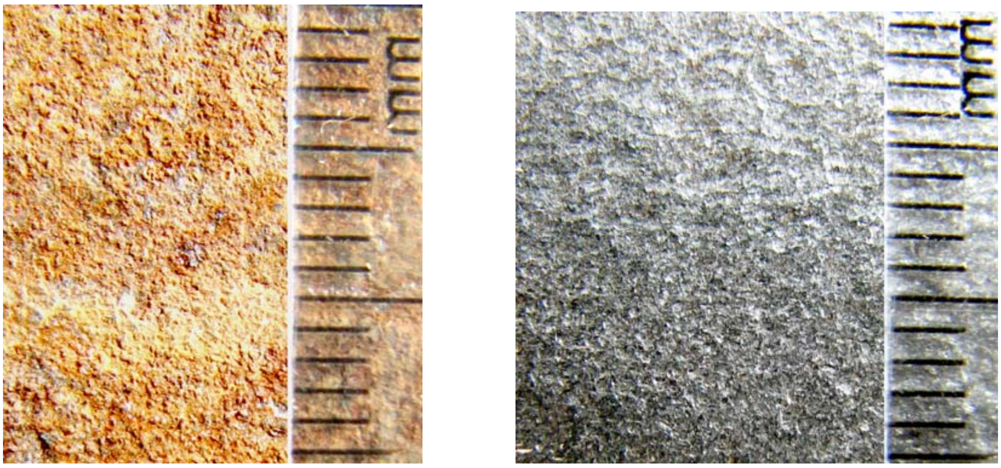


Figure 11 Corroded section of ABS-A steel plate used for evaluating corrosion removal performance of bristle blasting tool.

Cleanliness and Texture of Treated Surfaces

In Figure 12 the initially corroded surface is shown (top) along with a cleaned portion of the specimen after bristle blasting for comparison (bottom). Further inspection of these surfaces is shown at higher magnification in Figure 13a and indicates that while a significant depth of rust and corrosive pits appear on the initial specimen, the bristle blasted surface (Figure 13b) has a uniform, corrosion-free appearance, and no corroded pits remain on the cleaned specimen.

Figure 12 Initial corroded surface of as-received ABS-A specimen prior to cleaning (top) and after bristle blast cleaning (bottom).



(a) **(b)**

Figure 13 (a) Photograph depicting the extent of corrosion/pitting on the as-received surface of piping, and (b) cleanliness of the bristle blasted surface after corrosion removal.

In Figure 14, a scanning electron microscopic (SEM) image of the cleaned surface shows both the exposed substrate metal and the detailed surface texture. Careful examination of this image (50X) reveals that the surface is free of residual corrosion and that the characteristic impact crater appearing in Figure 7 (i.e., shovel micro-indentation) appears as a repeated pattern along the cleaned surface.

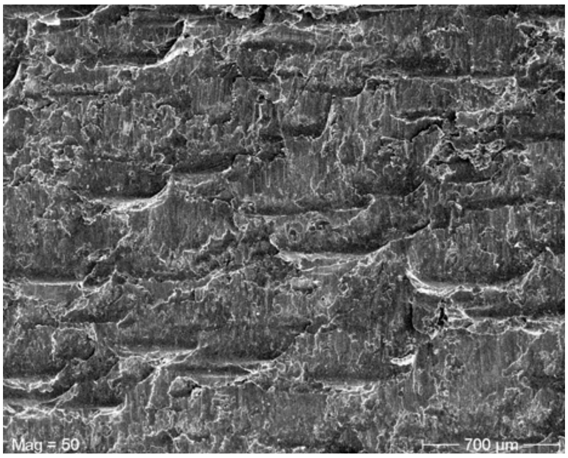


Figure 14 Scanning electron micrograph (magnification 50x) of ABS –A steel treated surface shown in Fig. 13(b). Bristle tool duty cycle: 25 min. of continuous service.

A direct comparison can now be made between the cleanliness of surfaces generated by the bristle blasting process with those published by the Society for Protective Coatings (SSPC) for power hand tools (SSPC VIS 3)[10]. Such a comparison clearly indicates that the surfaces generated by the bristle blasting process surpass the cleanliness that is characteristic of all power tool cleaning processes, including hand tool cleaning by power brushes, sanding discs, and needle guns. Cleanliness of the surfaces produced by bristle blasting also outperforms the cleanliness and texture expectations that are typical of power tool cleaning to bare metal, as cited in SSPC standard SP 11. That is, SP 11 allows corrosion to remain at the bottom of pits and has a minimum surface profile requirement of 25 microns, whereas no corrosive pits remain after bristle blasting, and the surface profile typically varies from 52 to 80 microns, as demonstrated in the next section.

Comparison can also be made between the bristle blasting process and the dry abrasive blast cleaning standards, namely SSPC VIS 1[11]. Careful examination of SSPC photographs for these visual standards indicates that the cleanliness performance of the bristle blasting process exceeds that of brush-off blast cleaning (SP 7), industrial blast cleaning (SP 14), and commercial blast cleaning (SP 6). The thoroughness of the bristle blasting process, however, does appear to be comparable with near-white blast cleaning (SP 10) and white metal blast cleaning (SP 5).

Material Removal Studies

The removal of corrosive layers via mechanical surface treatment processes is inevitably accompanied by the removal of base material as well. Excessive removal of substrate material, however, can compromise the integrity of the component/structure, especially in regions where thin cross-sections may exist. Therefore, considerable experimentation has been carried out to assess the material removal performance of the bristle blasting tool, and a portion of these results are shown in Figure 15 and Figure 16. The material removal process was carried out by using a 3-axis milling machine, and penetrating the rotating tool into a ground surface (ABS-A) at a specific/predetermined penetration depth. Subsequently, the tool was allowed to extract parent material for a pre-defined time interval (typically, 5 seconds) without interruption. After each interval, the specimen was weighed using a high resolution electronic balance, and the difference in weight of the specimen (equal to the material removed) was recorded.

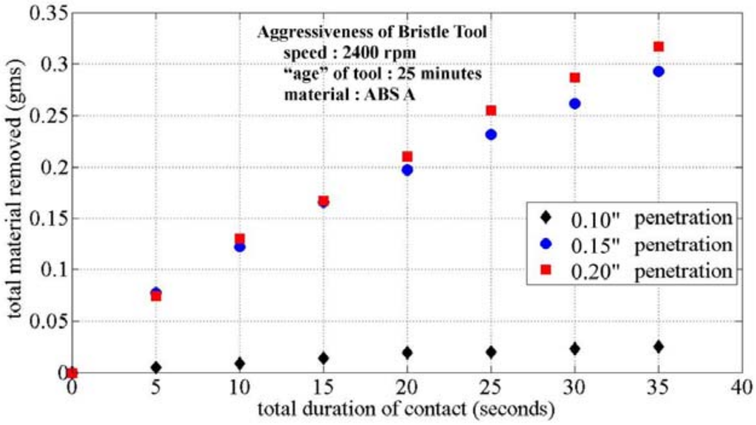


Figure 15 Measured material removal rate for ABS-A specimen, using bristle blasting tool having a 25 minute duty cycle at different depths of penetration. Approximate bristle tool specifications: face width: 22 mm, hub radius: 27.5 mm, bristle wire diameter: 0.73 mm, bristle length: 27 mm, total bristle population ~480.

In Figure 15 results are shown for the material removed at three different penetration depths by a tool that has been subjected to a duty cycle of 25 minutes of continuous use. Thus, the material removed at a penetration depth of 0.1 in. (diamond), 0.15 in. (circle) and 0.2 in. (square) are reported and indicate that the material removal performance of the tool is minimal at shallow penetration (i.e., 0.1 in.) but increases significantly at the deepest penetration depths (i.e., 0.15 in., and 0.2 in.) A similar experiment was carried out in order to assess the role that the age of the tool plays in material removal performance. These results appear in Figure 16, where the material removed from a specimen by tools that have acquired

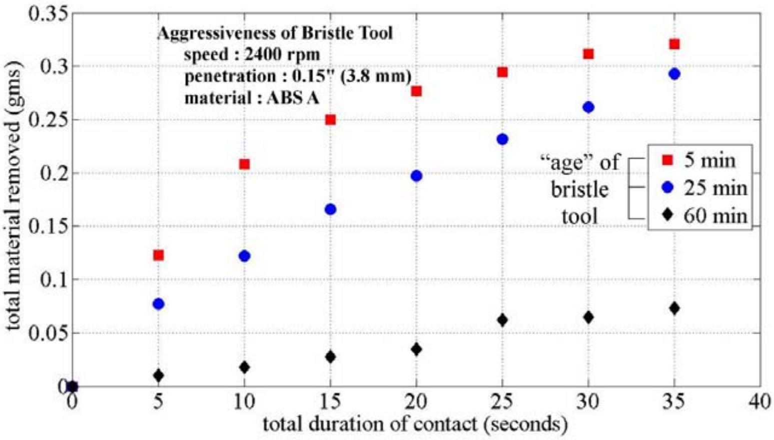


Figure 16 Measured material removal rate for ABS-A steel specimen, using bristle blasting tools having various periods of continuous service. Approximate bristle tool specifications: face width: 22 mm, hub radius: 27.5 mm, bristle wire diameter: 0.73 mm, bristle length: 27 mm, total bristle population ~480.

three different duty cycles, namely 5 minutes (square), 25 minutes (circle) and 60 minutes (diamond) of service is shown. In each case, the experiment was performed at a nominal penetration depth of 0.15 in. The results suggest that as the period of tool use increases, bristle tips are prone to eventual wear and/or breakage, which progressively reduces the material removal capacity of the tool.

Surface Texture and Assessment of Tool Life

The use of various tools and media for surface cleaning processes inevitably yields a characteristic surface appearance or “signature” that is peculiar to the contact/interaction that occurs along the interface of the tool and workpart However, finer details of the surface morphology cannot be visually resolved and, therefore, a host of surface texture parameters have been proposed for quantifying architectural surface features with greater precision. To this end, the *average peak-to-valley texture parameter* R_z is often used for measuring the “anchor profile” of cleaned surfaces prior to the application of paints and coatings.

In order to develop an understanding of the detailed surface texture that is generated by the bristle blasting process, surfaces are prepared by a manual, user-applied steady load as depicted in Figure 10. That is, the specimen was subjected to a *single pass* (that is, a single horizontal band), and the surface texture parameter R_z within the band was subsequently measured at several uniformly-spaced sampling positions that lie along the direction of tool movement using standard laboratory equipment (Mitutuyo Surface Roughness Tester SurfTest SJ-301). The results shown in Figure 17 for three different user-applied penetration depths,

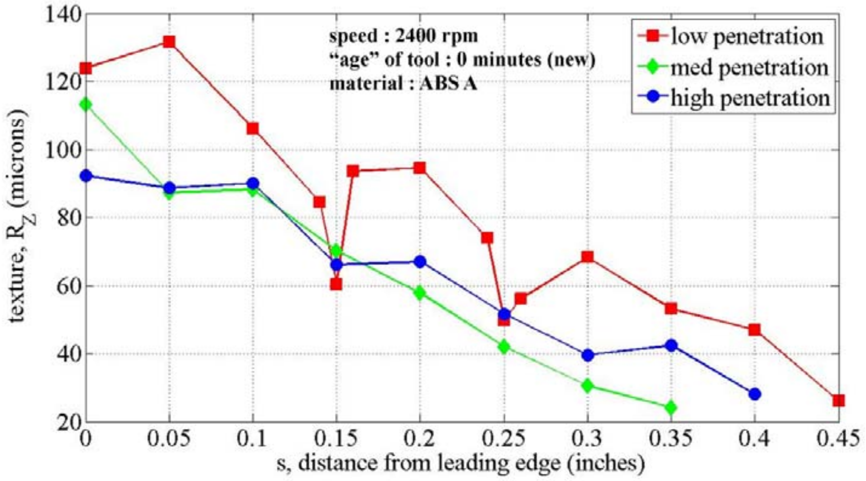


Figure 17 Measured surface profile at several locations within the contact region bandwidth for a single pass of bristle blasting tool. These data show the role that increased user-applied penetration depth plays in generating surface profile.

namely, low (square), medium (diamond), and high (circle), and indicate that coarsest texture is obtained at the least penetration. A noticeable decline in texture measurement (approximately 20% reduction) is observed however, at the deepest user- applied penetration

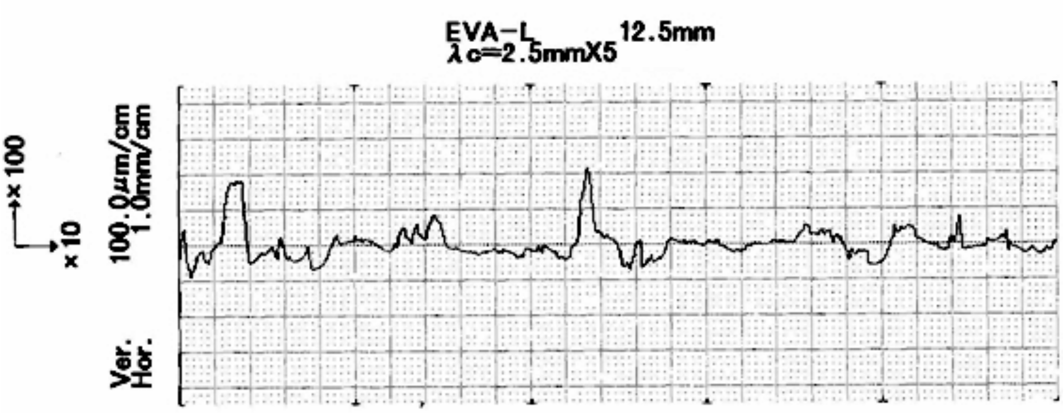


Figure 18 Topographic profile of a bristle blasted surface traced by a surface profilometer along a single user-applied pass. The approximate position within the band corresponds to s=0.1 in. (see Figure 17).

depths. Finally, the actual surface profile that was recorded along the approximate coordinate position s = 0.1 in. (see Figure 17) is shown in Figure 18, which illustrates the topographical nature of a bristle blast surface.

As one may expect, the texture generated by bristle blasting tools will vary as the duty cycle of the tool increases due to filament tip wear and/or breakage. This aspect of tool performance has been examined by manually cleaning corroded ABS-A (Figure 11) and periodically measuring R_z using standard press-film replica tape. Thus, the relationship between duty cycle and profile performance is shown in Figure 19 and indicates that a new tool (i.e., as-received) generates an average surface profile of $R_z \approx 80$. As the duty cycle of the tool increases, however, the surface texture regularly declines and, after approximately one hour of service, is reduced to $R_z \approx 52$.

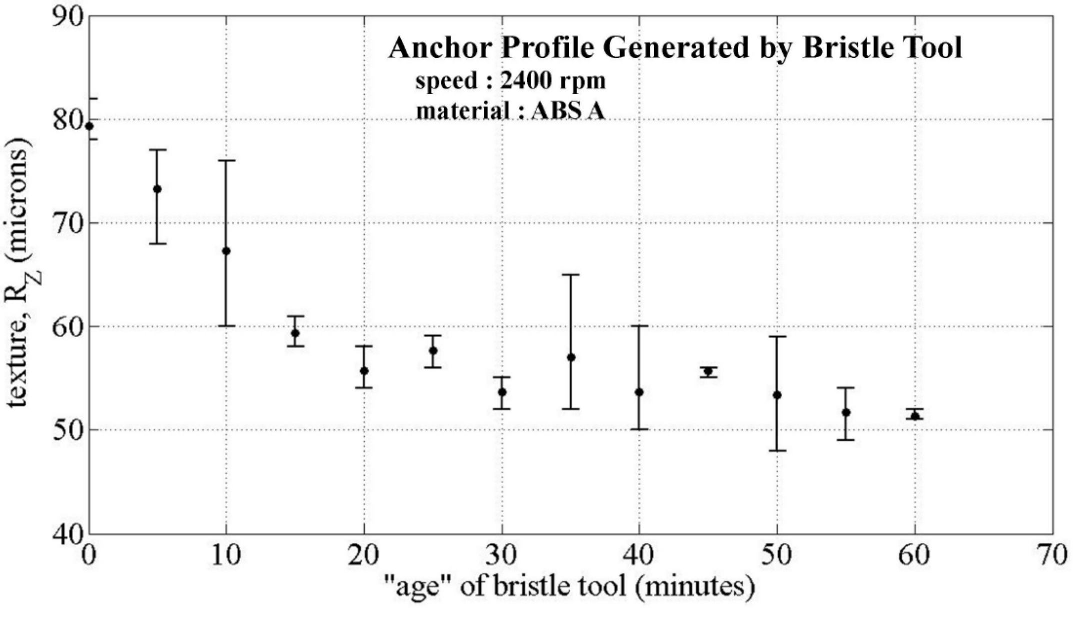


Figure 19: Variation of surface texture/anchor profile as bristle blasting tool progressively ages. Surface profiles were recorded using standard press-film replica tape. Approximate bristle tool specifications: face width: 22 mm, hub radius: 27.5 mm, bristle wire diameter: 0.73 mm, bristle length: 27 mm, total bristle population ~480.

SUMMARY AND CONCLUSION

Bristle blasting is a viable, aggressive process for removing corrosive layers while simultaneously generating an anchor profile. The corrosion removal capacity and surface cleanliness performance of the bristle blasting process is on an equal par with norms and standards that are commonly associated with grit blasting operations.

A direct comparison of bristle blasting tool performance with SSPC VIS 3 in conjunction with the power hand tool cleanliness standard SP 11 clearly indicates that the bristle blasting process surpasses the cleanliness and profile that is characteristic of all power tool cleaning processes, including hand tool cleaning by power brushes, sanding discs, and needle guns. Furthermore, comparison of the bristle blasting process with dry abrasive blast cleaning standard SSPC VIS 1 shows that performance of the bristle blasting process exceeds that of brush-off blast cleaning (SP 7), industrial blast cleaning (SP 14), and commercial blast cleaning (SP 6). Thoroughness of the bristle blasting process, however, appears to be on an equal par with near-white blast cleaning (SP 10) and white metal blast cleaning (SP 5). Thus, the disparity of the bristle blasting process with norms/standards cited in SP 11 suggests that a re-evaluation of this document is needed in order to accurately convey the performance of bristle blasting processes to the corrosion/surface finishing community.

ACKNOWLEDGEMENT

The authors gratefully acknowledge support provided by the project sponsor, Monti Werkzeuge, Bonn, Germany, and the technical advice offered by Mr. Werner Montabaur.

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