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BRISTLE BLAST SURFACE TREATMENT OF WELDED JOINTS FABRICATED FROM COMMERCIAL SHIP CONSTRUCTION STEEL

Professor Robert J. Stango, Ph.D. (robert.stango@mu.edu),
Professor Raymond A. Fournelle, Ph.D., and Jorge A. Martinez
Mechanical Engineering Department
1515 West Wisconsin Avenue
Marquette University
Milwaukee, WI 53233 USA

ABSTRACT

The fabrication, repair and maintenance of steel structures are ongoing concerns that must be regularly addressed in order to sustain a world-wide infrastructure that relies on marine vessels for both commercial transportation and national security needs. To this end, great care is exercised in producing and protecting welded joints because the integrity of these seams provides a cornerstone for ensuring their structural longevity. At the same time, maintenance engineers in the ship building industry are faced with the continual need for deploying new methods for surface preparation that will not compromise the surface cleanliness and anchor profile requirements that are necessary for proper adhesion of paints and coatings.

In this paper, the recently developed bristle blasting process is used for cleaning and preparing welded joints fabricated from both ABS-A and AH-36 steel, which are commonly used in the commercial ship building industry. Overall principles of the process are briefly reviewed and details concerning the mechanical function of the tool are examined. Performance of the bristle blasting process is examined within the context of both cleaning and simultaneously generating a receptive anchor profile along the seam of welded joints. The aggressiveness/material removal capacity of the tool is measured and reported using standard tool operating conditions, and the texture and surface morphology generated by the bristle blasting process is examined along the crown and toe of the weld. Finally, the overall cleanliness of surfaces generated by bristle blasting is assessed by a direct comparison with visual standards that are commonly used for training and certification purposes in the surface preparation community.

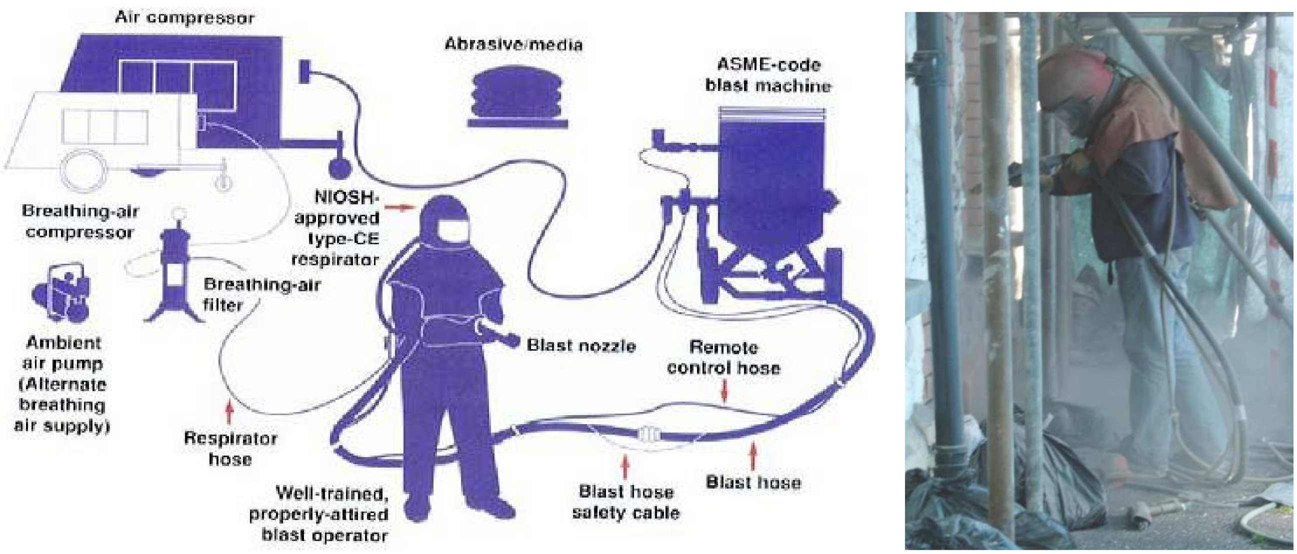
KEY WORDS

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

INTRODUCTION, BACKGROUND, AND OBJECTIVES

Shipyard fabrication, refurbishment, and repair operations require the use of many different types of tools for cleaning and preparing surfaces that must satisfy stringent requirements for proper adhesion of paints and coatings. To this end, engineers are continually looking for new methods that can both satisfy these requirements and simultaneously meet the ever increasing demand for maximizing user safety while minimizing the impact on eco-systems. At the same time, cost constraints dictate that these tools and methods generate surfaces that are coating-ready with minimal expenditure of time and effort. Often, this involves the use of tools that have the capability of simultaneously satisfying two important criteria in a single step, namely, surface cleanliness, and anchor profile requirements. Surprisingly, very few tools/processes exist that can meet this dual-purpose requirement. Specifically, grit blast and needle gun are among the most widely used surface preparation processes that can meet both criteria in a single operation. However, as noted in the following discussion, each of these methods has significant drawbacks that can inhibit/prevent their use in a working environment.

The implementation of grit blasting (reference Figure 1), for example, has three stages of operation that must be carried out in order to bring the task to completion. First, set-up requires that the worker connect and transport media and fresh air hose lines from the source location to the site where grit blast cleaning is performed. Air quality and blast hose

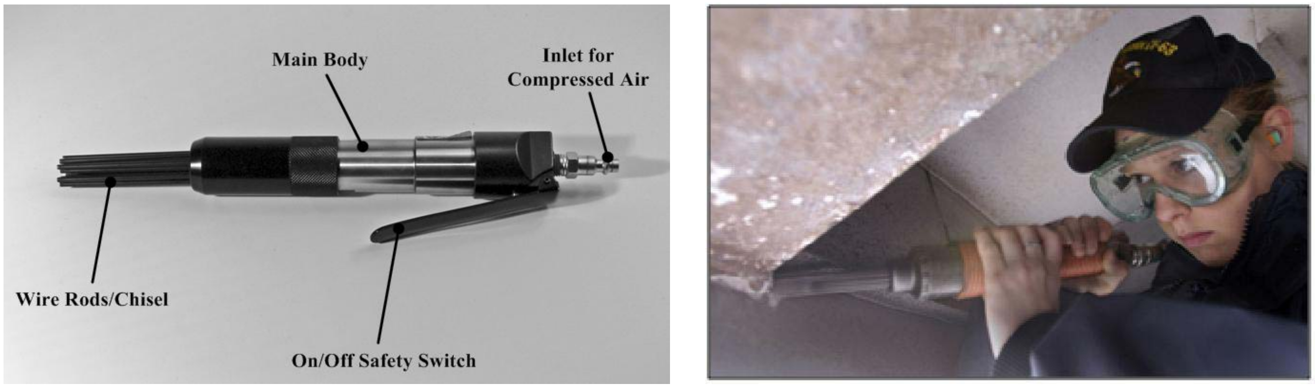


(a) **(b)**

Figure 1 (a) Equipment/apparatus required for carrying out grit blast process, and (b) actual grit blast working environment/application

performance must then be assessed/adjusted in order to ensure that safe and efficient conditions are provided for the worker prior to carrying out the blast operation. Second, the actual cleaning operation is then carried out by a worker who performs the task while encapsulated in an environmentally regulated safety suit. Upon completing the task, an inspection is required in order to determine if final touch/spot cleaning may be required. Third, the spent grit must be recovered from the worksite, properly disposed, and the blast equipment must be disassembled, cleaned, and removed from the work site.

Use of the needle gun (also termed “scaler”) shown in Figure 2 is inherently simple, and involves the use of a hand operated power tool having wire rods whose tips rapidly oscillate while making contact with the contaminated surface. The noise and vibration that issues from this pneumatic tool during use is problematic, and requires that ear protection be worn by both the user and those in close proximity of the cleaning operation. Also, worker exposure to

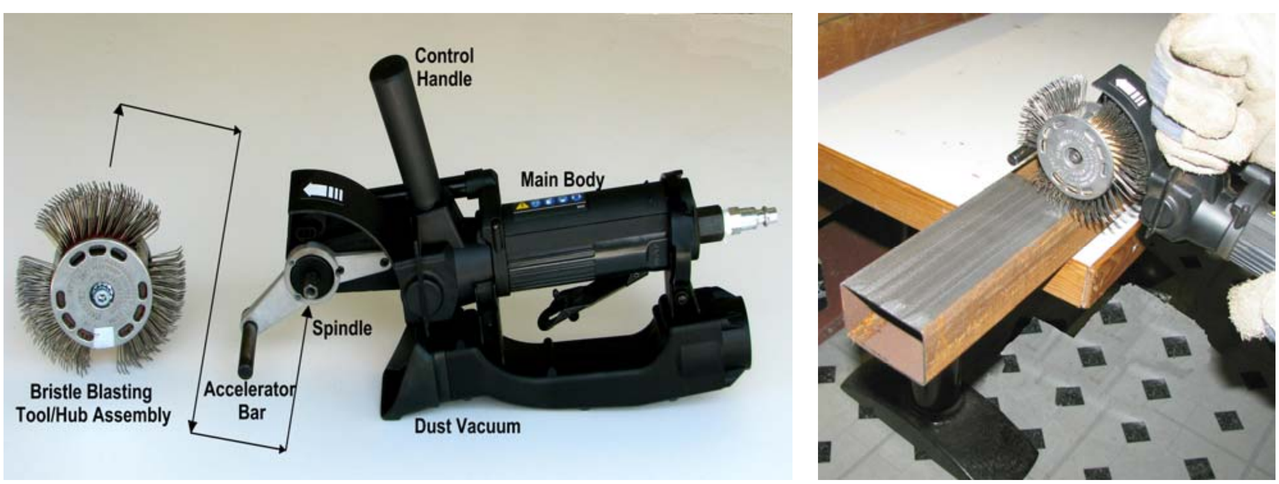


(a) **(b)**

Figure 2 (a) Typical hand operated needle gun power tool, and (b) actual needle gun cleaning application.

vibration must be monitored, due to hand-trauma injury/disorders that have been documented in the literature. That is, strict limitations have been recommended [1] for the maximum duration of exposure that an individual can endure throughout a work-shift period.

More recently, a *wire blast* process has been developed that can both clean surfaces and generate an anchor profile in a single operation. As shown in Figure 3, this involves the use of a hand operated power tool having a rotary wire disk that rotates at approximately 2600 rpm. During use, the rotary tool is placed in contact with the contaminated surface, whereupon each wire tip strikes and immediately retracts from the workpart surface. This impact/rebound of



(a) **(b)**

Figure 3 (a) Components of hand operated bristle blasting power tool, and (b) actual cleaning application

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bristle tips generates a multitude of impact craters that have been likened to those formed during grit blast cleaning processes [2]. That is, repeated impact of wire tips with the target surface leads to both corrosion removal and exposure of fresh substrate, along with a micro-indentation pattern similar to grit blast processes. In addition, recently reported studies indicate that paint adhesion performance is nearly identical for the two different processes as well [3,4]. However, little or no information has been published regarding the performance of bristle blasting on welded joints. Consequently, little is known about the correct method of use, the thoroughness of cleaning, and the profile imparted to the weld bead for this important class of applications.

The objective of this technical paper is to explore the performance of bristle blasting process when used for weld cleaning applications that are commonly encountered in the commercial ship construction industry. Specifically, production-quality welded joints are fabricated from ABS A steel and AH 36 steel, and a series of tests are performed that both characterize the weld, and help assess the cleanliness, texture, and efficiency that one may expect for this type of bristle blast cleaning application. In addition, the performance/dexterity of the tool is assessed by using the tool along perpendicular (90 deg.) weld seams, which is a helpful measure of evaluating the function of the tool in corner/recessed areas where workspace restrictions are present.

REVIEW OF BRISTLE BLASTING PROCESS

Mechanical Aspects of Synchronized Wire-tip Impact

Bristle blasting is a recent innovation for surface preparation processes and, therefore, the basic principles of operation are briefly reviewed in this section. A key feature of the tool is embodied in the interaction between bristle tips and the accelerator bar, which appears in

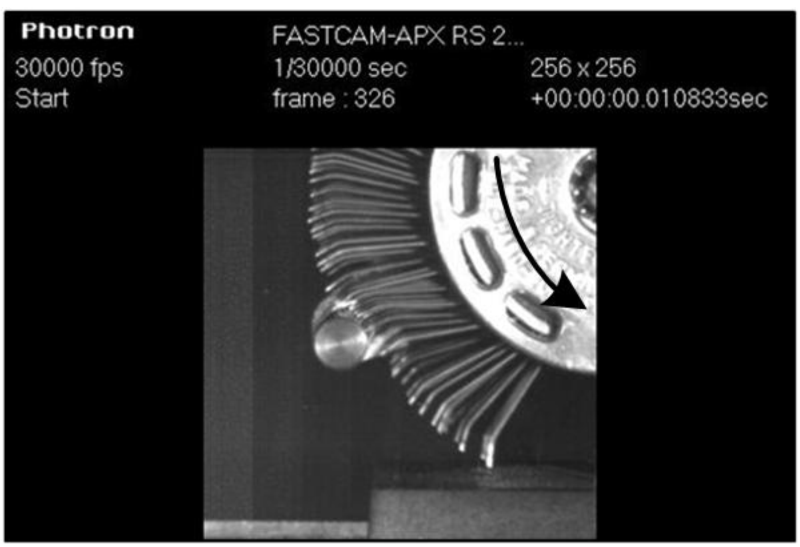


Figure 4 Photograph/cell taken from high speed digital camera illustrating bristle tips in contact with accelerator bar, and subsequent release toward workpart surface.

Figure 4. That is, as the bristle blasting tool rotates (counterclockwise), wire tips collide with the cylindrical (accelerator) bar, which results in bristle "spring-back". Detailed examination of

the collision process has been viewed via high-speed digital camera [5] and is shown schematically in Figure 5. That is, after contact is made with the accelerator bar, the bristle retracts (rearward) as shown in Figure 5a. This retraction leads to the storage of additional energy that will ultimately be returned to the bristle after the wire tip is released from the surface of the bar, as shown in Figure 5b. Thus, forward movement of the bristle is

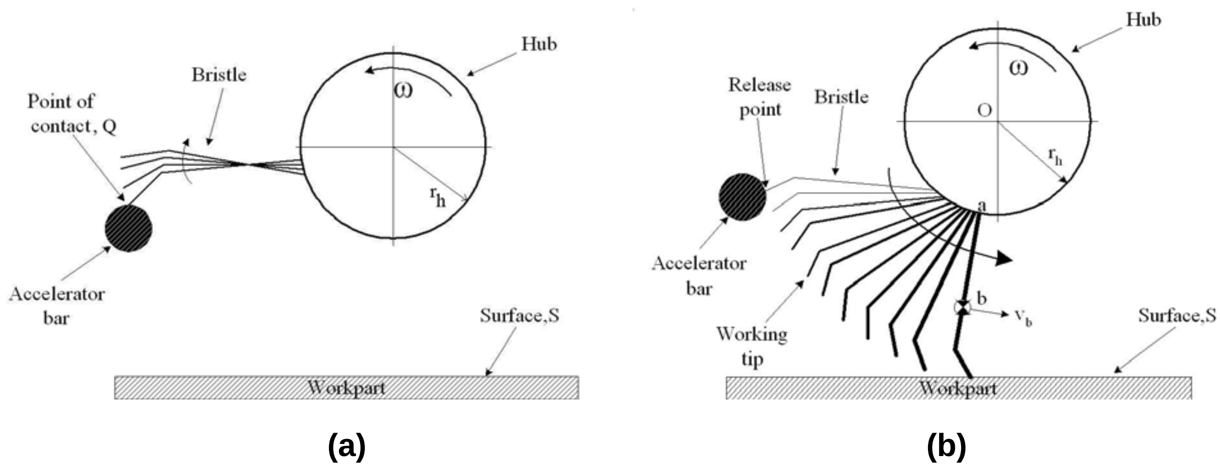


Figure 5 (a) Depiction of bristle tips initial contact with the accelerator bar and subsequent rear-ward retraction, and (b) acceleration of bristle tip towards the target surface upon release from the accelerator bar.

synchronized so that maximum velocity of the tip is reached upon impact with the target surface. Upon impact, sharpened bristle tips strike the steel surface and again retract, which generates a multitude of craters that resemble those formed during grit blast processes [6]. These repetitive impacts lead to removal of corrosion/contaminants, expose of fresh substrate, and produce a receptive surface profile that is required for subsequently applied paints and coatings. Detailed calculations have been carried out that provide a helpful comparison

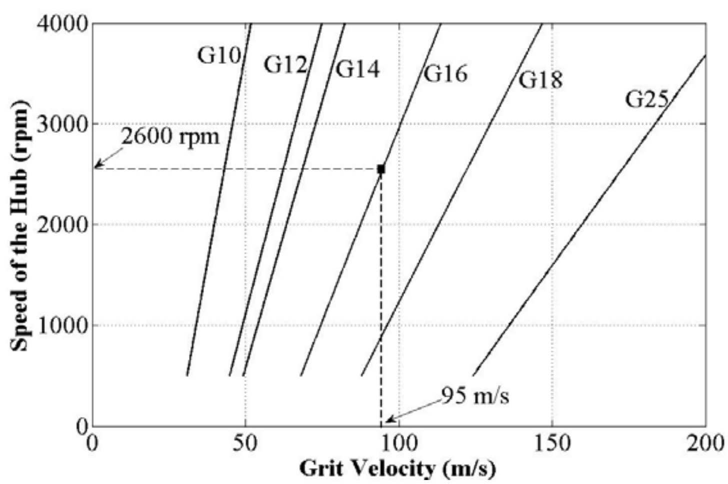


Figure 6 Relationship between spindle speed and grit velocity for various steel media. (Note: spindle speed 2600 rpm corresponds to grit velocity of 95 m/s for G16 media, and wire bristle having the following dimensional data: face width: 22 mm, hub radius: 27.5 mm, bristle wire diameter: 0.73 mm, bristle length: 27 mm, total bristle population ~480).

between the energy generated by grit blast versus wire blast processes [7]. The results of this study are summarized in Figure 6 for several different (steel) grit sizes when compared to various spindle speeds of the bristle blasting tool. As shown in Figure 6, when operating at 2,600 rpm, the currently designed bristle blasting tool generates an equivalent energy to G16 steel grit having a nozzle exit velocity of 95 m/s.

Implementation of Bristle Blasting Process [4, 7, 8]

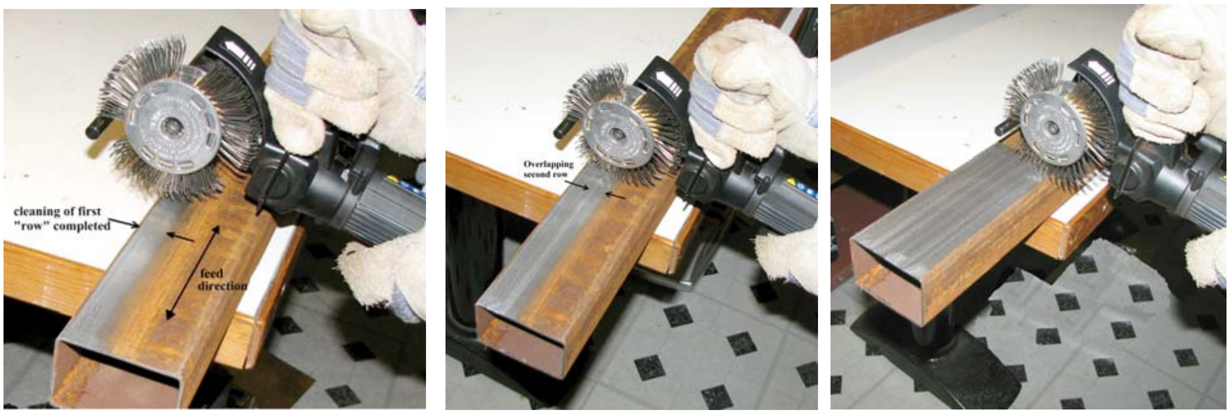
All manual surface treatment processes require dexterity, visual acuity, and a basic understanding of key parameters that affect the performance of surface finishing equipment. Training and experience are, therefore, important factors that enable users to develop skills that are needed for a successful 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. 7. 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. 7a). 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. 7a, 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. 7a. 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.7b, 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 7 Recommended use of bristle blasting tool for corrosion removal. First, a horizontal row is prepared (Fig. 7(a)) using minimal applied force and steady feed rate. The process is then repeated by overlapping the second row (Fig. 7(b)) with the previous row that was cleaned. Finally, the entire surface is cleaned (Fig. 7(c)) by repeatedly overlapping each row with the previously cleaned region until full coverage is completed.

<u>Completing the corrosion removal process</u>

Corroded components can be completely cleaned by repeating the previously described procedure. Thus, as shown in Fig. 7c, 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.

CHARACTERISTICS OF AS-RECEIVED WELDED JOINTS

Details concerning the production-quality welded joints that were used in this study appear in Figure 8a and 8b for ABS-A plate material and in Figure 9 for AH-36 plate material. In each case, welding was performed on both sides of 0.5 in. (1.3 cm.) thick plate using a wire feed machine, and the filler/rod metal used was Lincoln 71M, with CO_2 shielding gas. In Figure 8a,

(a) **(b)**

Figure 8 (a) Front weld bead and weld pool segment (inset), and (b) rear weld bead of ABS-A welded specimens.

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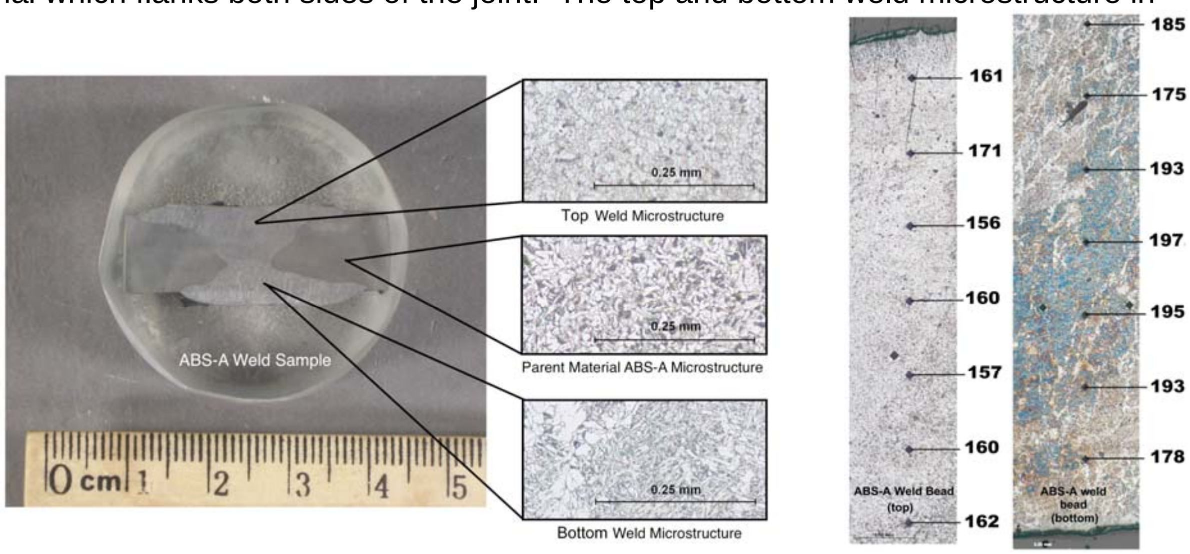
the weld bead on the front side of the ABS-A plate is shown, which depicts typical spatter and slag that is commonly generated during the formation of welded joints. Contour of the weld pool is magnified in Figure 8a (red inset) and exhibits typical weld-flow/solidification lines.

Figure 9 Front weld bead and weld pool segment (inset) of AH-36 welded specimen.

Similarly, the reverse side of the ABS-A welded plate is shown in Figure 8b, which exhibits like characteristics. In Figure 9, the front weld bead of the AH-36 plate is shown, whereby weld spatter, slag, and the contour of the weld pool (red inset) are similar to those shown for ABS-A plate. Both plate materials exhibit minimal corrosion, since the specimens were not subjected to a corrosive environment for extensive time duration.

A metallographically prepared profile/cross section of the ABS-A welded joint is shown in Figure 10a along with the microstructure of the top weld bead, bottom weld bead, and parent material which flanks both sides of the joint. The top and bottom weld microstructure in



(a) **(b)**

Figure 10 ABS-A weld specimen (a) Cross-section of metallographically prepared specimen illustrating top weld bead, base metal (parent material), and bottom weld bead, and (b) Vickers microhardness measurements of top and bottom weld beads.

Figure 10a are typical of the low carbon weld rod (Lincoln 71M) used. Both welds exhibited a dendritic pattern of ferrite grains with fine and coarse grain structures. The bottom weld bead exhibited a finer grain structure, which is reflected in slightly higher Vickers (500 gm. load) microhardness values, as shown in Figure 10b. The microstructure of the ABS-A base metal is typical of good quality hot-rolled low-carbon steel, and rendered an average Vickers hardness measurement of 155, which is (up to) 25% less than select measurements that are recorded along the weld bead. As such, it consists of grains of ferrite with some regions of pearlite, and does not exhibit excessive banding.

The top and bottom weld microstructure for the AH-36 shown in Figure 11a are typical of the low carbon weld rod (Lincoln 71M) that was used. Both welds exhibited a dendritic pattern

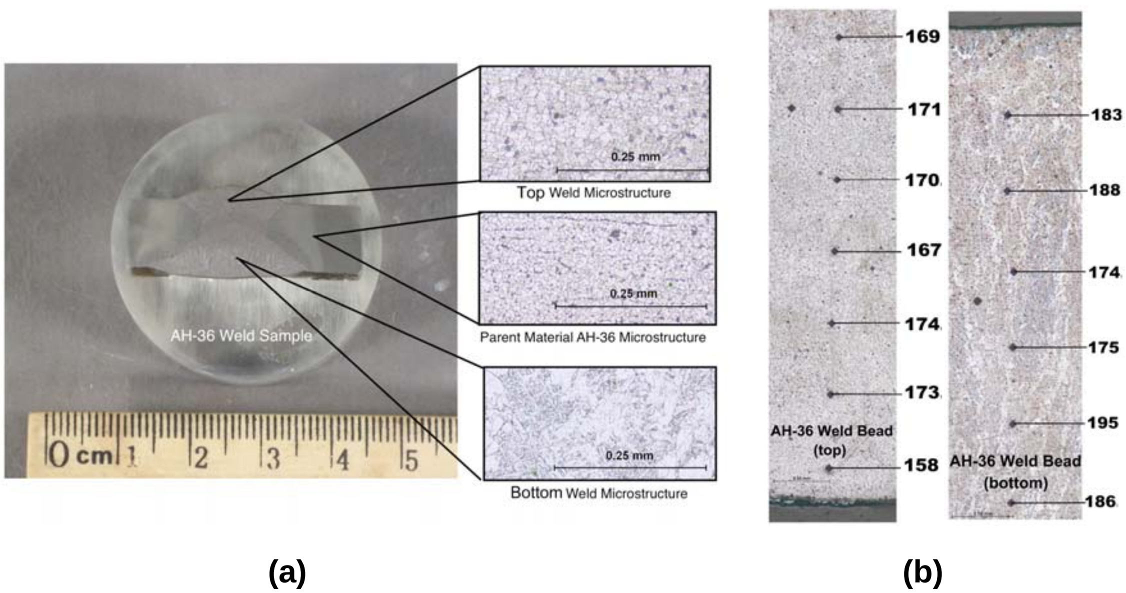


Figure 11 AH-36 weld specimen (a) Cross-section of metallographically prepared specimen illustrating top weld bead, base metal (parent material), and bottom weld bead, and (b) Vickers microhardness measurements of top and bottom weld beads.

of ferritic grains with coarse and fine grain boundaries. The bottom weld bead again exhibited a finer grain structure, which is reflected by a slightly higher Vickers microhardness, as shown in Figure 11b. The microstructure of the AH-36 base metal is typical of hot-rolled low-carbon steel and rendered an average Vickers hardness measurement of 182 which, typically, varies by less than 10% with the weld bead measurement. Also, the base metal exhibited a higher degree of banding than the ABS-A, but it was not viewed as excessive.

EXPERIMENTAL PROCEDURE, RESULTS, AND DISCUSSION

In this section, the experimental procedures that were used for evaluating three different aspects of welded joint surface treatment are examined, namely

- material removal performance
- profile/texture, and
- cleanliness.

Taken together, these results provide a means for assessing the efficiency and performance that one may expect for bristle blast cleaning of welded joints fabricated from ABS-A and AH-36 ship steel.

Material Removal Performance

The overall set-up that is used for measuring material removal performance of welded joints is shown in Figure 12 and consists of a three-axis milling machine that has been reconfigured/adapted for evaluating a wide variety of surface preparation tools. In the current set-up, the workpart is affixed to the milling table platform, which is readily programmed to penetrate the rotating bristle blasting tool while simultaneously moving along the weld bead at

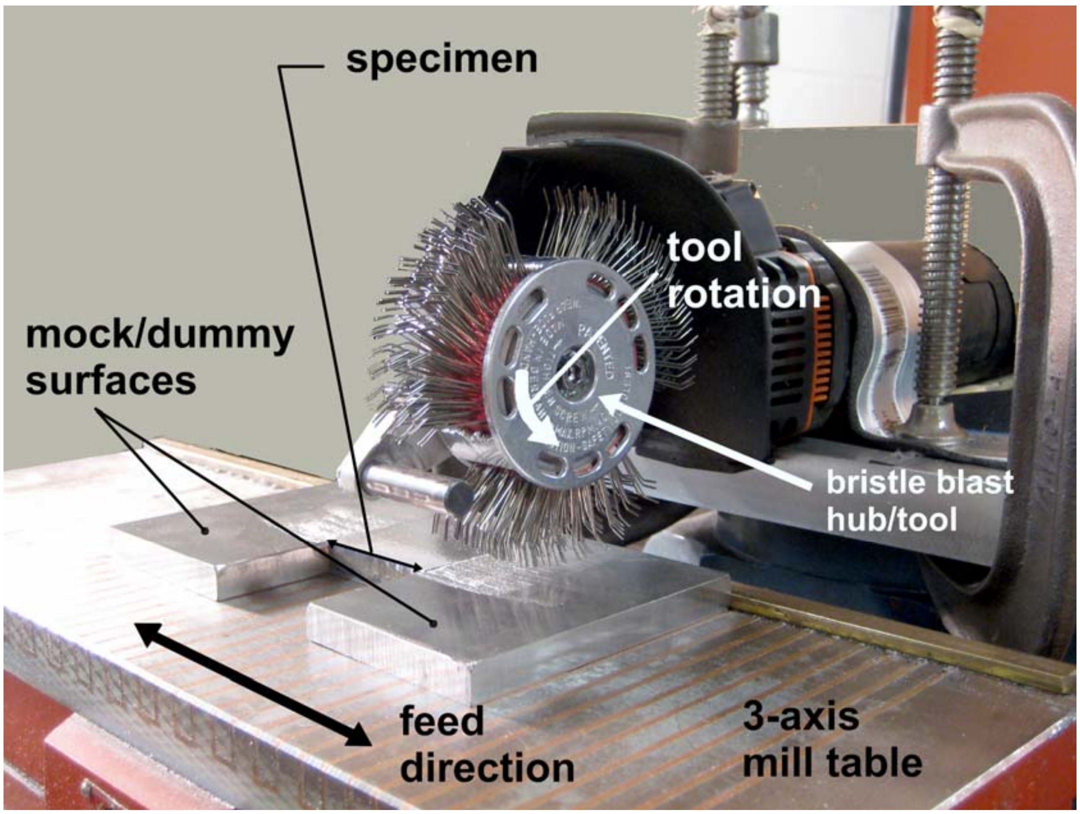
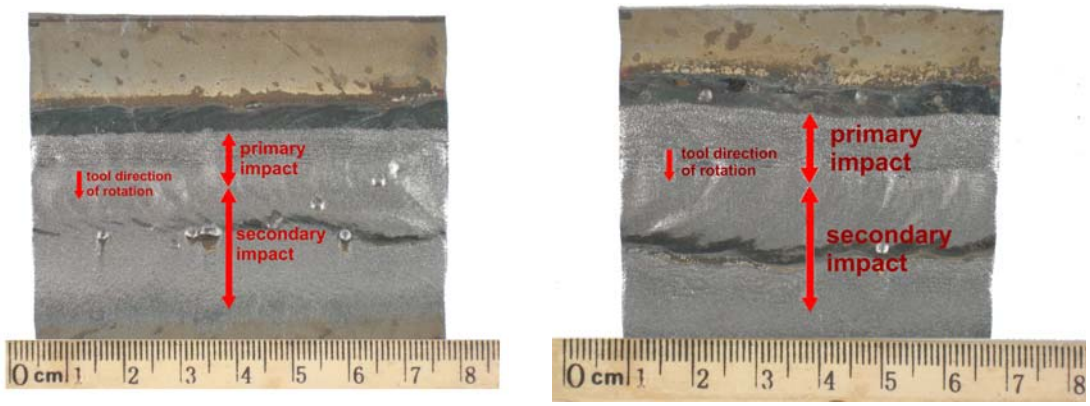


Figure 12 Experimental set-up of 3-axis mill used for material removal measurement studies.

a prescribed feed rate. The specimen itself is flanked on both sides by a "mock", or "dummy" workpart, which eliminates "edge effect" inaccuracies that can arise as the rotating tool repeatedly passes across the fore and aft edges of the specimen surface. At the conclusion of each pass, the workpart is removed from the table, and the material extracted from the weld bead (i.e., gram-weight) is precisely measured using a high-resolution electronic balance. The process is then repeated for several consecutive passes, while utilizing the same initial tool penetration and table feed rate for all subsequent trials.

ABS-A and AH-36 material removal specimens are shown In Figures 13a and 13b respectively, which illustrates the exact contact region where bristle tips have traversed the weld bead. Careful examination of each figure indicates that the uppermost portion of the weld

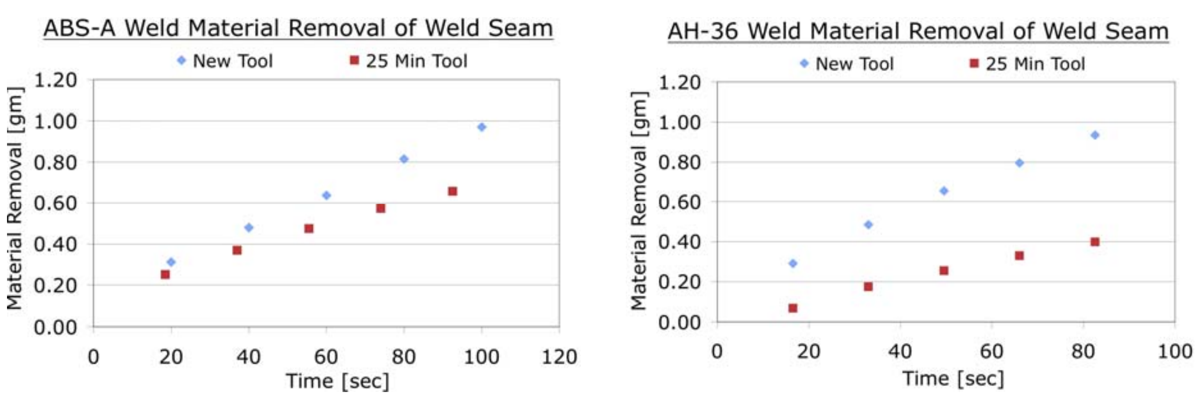


(a) **(b)**

Figure 13 Bristle blast surface of specimen used in material removal study for (a) ABS-A welded joint, and (b) AH-36 welded joint

remains untouched by the tool, whereas the crown of the weld bead corresponds to the *primary impact* site of bristle tips. Furthermore, lower portions of the weld bead as well as a segment of the parent base metal bear *secondary impact* craters, which are indicative of subsequent (less formative) “rebounds” of the bristle tip. Finally, it is apparent that bristle tips have not engaged the lower region of the weld toe, because “down-stream” portions of the contact zone are partially masked by higher elevations of the weld itself. In summary, based upon the observed tool contact pattern shown in Figures 13a and 13b, it is conjectured that the material removed (gram-weight) from the contact region will largely be associated with the weld bead itself, whereas the secondary contact of bristle tips with the base metal surface will play a minimal role in the material removal process.

In Figures 14a and 14b results are shown for weld material removed from the ABS-A and AH-36 specimens, respectively. In each case, material removal performance is shown for both “new” (i.e., as-received) tools and for tools that have acquired nearly ½ hr. of continuous use.



(a) **(b)**

Figure 14 Weld material removal (gram weight) versus duration of tool contact (seconds) for new tool and 25 minute duty cycle tool (a) ABS-A weld seam, and (b) AH-36 weld seam.

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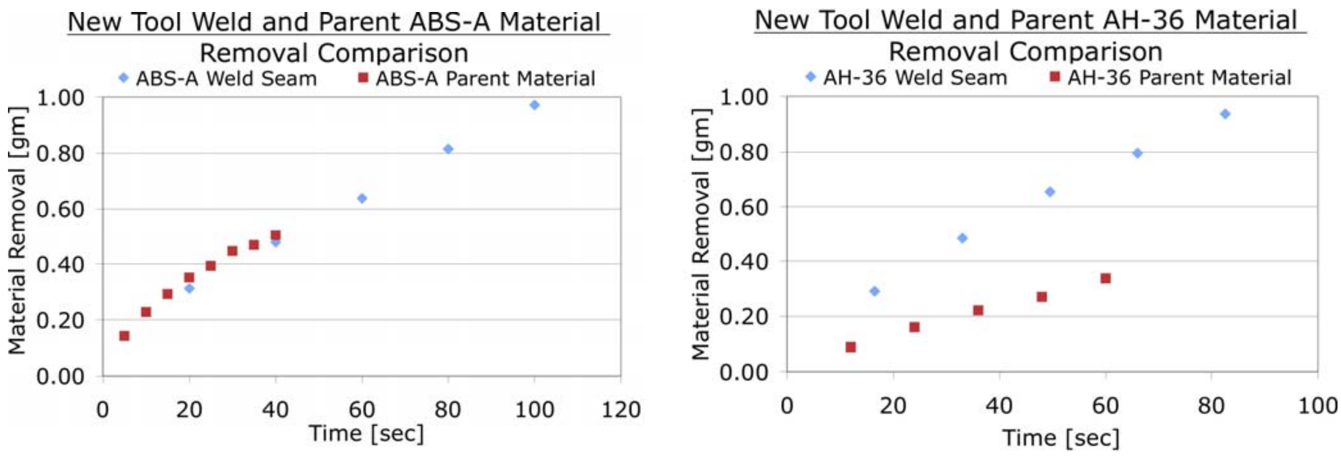
Accordingly, a decline in material removal performance is readily detected, which is attributed to the progressive wear of bristle tips as the tool accrues duty cycles associated with repetitive impact [4].

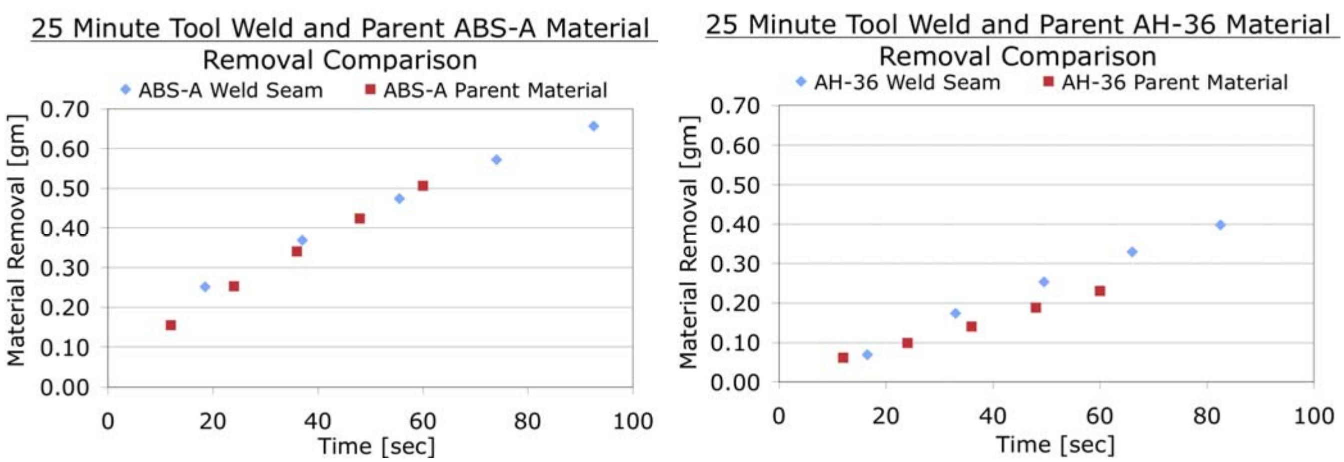
Further information is needed in order to help assess the *relative performance* of bristle blasting tools when used for cleaning base metal (parent material) in comparison with the



(a) **(b)**

Figure 15 Comparison of weld seam and base metal material removal performance using new tool (a) ABS-A welded specimen, and (b) AH-36 welded specimen.

welded joint. Thus, a direct comparison of these two different material removal processes is shown in Figures 15a and 15b for ABS-A and AH-36 steels, respectively. In each case, the results are shown for as-received bristle blasting tools, and indicates that material removal performance is essentially unchanged for ABS-A (Figure 15a), whereas weld bead material removal occurs at nearly twice the rate of parent material for AH-36 steel (Figure 15b). This



(a) **(b)**

Figure 16 Comparison of weld seam and base metal material removal performance for 25 minute duty cycle tool (a) ABS-A welded specimen, and (b) AH-36 welded specimen.

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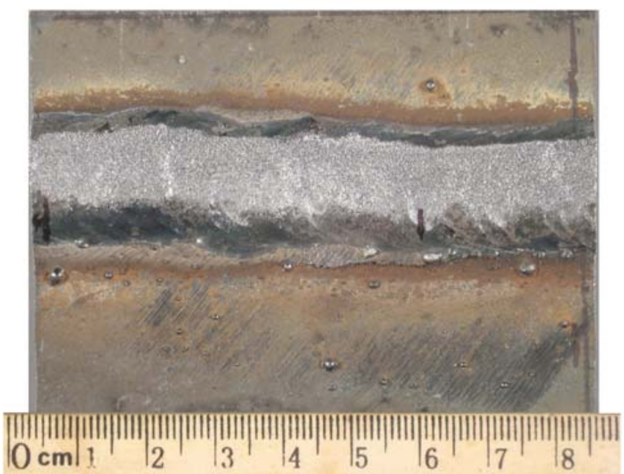
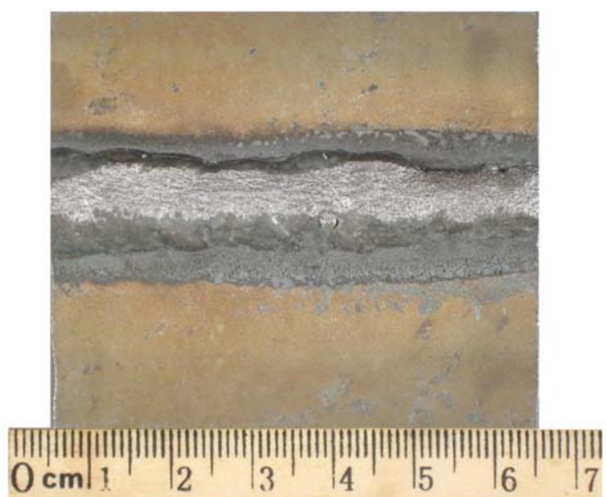
result is intriguing, and the findings are again repeated for bristle blasting tools that have acquired 25 minutes of continuous use in Figures 16a and 16b. Examination of these results indicates that, once again, the material removal performance is essentially unchanged for ABS-A (Figure 16a), whereas weld bead material removal occurs more rapidly (approximately 15%) than that of parent material for AH-36 steel (Figure 16b). In summary, these results indicate that both the weld and parent material of ABS-A steel are uniformly/equally abraded during the surface preparation process, whereas the weld bead material of AH-36 steel is preferentially abraded when compared to parent material during the surface preparation process. This propensity for greater material removal along the weld bead (AH-36 steel only) suggests that weld/spatter cleaning inevitably occurs more rapidly than base metal, thereby leading to preferential weld cleaning and reduced process time.

Profile/Texture Studies

The crown of the weld joint provides an adequate region for assessing the actual profile that is imparted to the weld seam by the bristle blasting tool. Therefore, a select number of specimen weld crowns were cleaned manually, and the surface profile was measured using the Mitutoyo Surftest SJ 301stylus type surface roughness measurement instrument. Typical profiles of the cleaned weld crowns that were generated using an as-received bristle blasting tool (single pass) are shown in Figure 17 for both ABS-A (Fig.17a) and AH-36 (Fig.17b). In each case, the contact region is narrow and indicates that the prepared surface has been generated by single (primary) impact between the bristle tips and weld bead surface. Also, remnants of the (solidified) weld flow lines still remain visible after the surface treatment, which is characteristic of the uniform, non-selective, and gradual material removal performance of the bristle blasting process. In Figure 18 the measured results for surface texture parameter Rz is shown for ABS-A and AH-36 steel using both as-received tools and service accrued (25 min.) tools. In each case the results exhibit similar trends, and indicate that the mean profile Rz = 90µm is routinely obtained for as-received tools, whereas the mean profile generated by tools that have acquired nearly ½ hr. of service corresponds to Rz = 50µm.





(a) **(b)**

Figure 17 Single-pass profile generated along weld crown of (a) ABS-A welded specimen, and (b) AH-36 welded specimen.

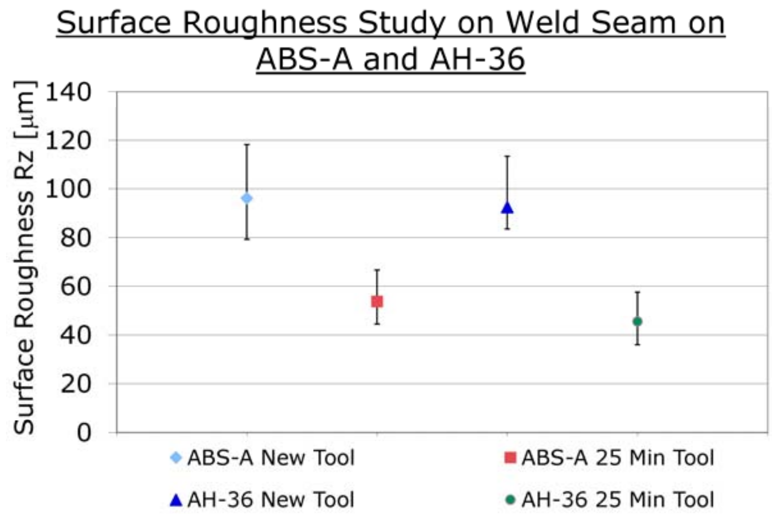


Figure 18 Measured surface roughness along weld crown using both new tools and 25 minute duty cycle tools on ABS-A and AH-36 weld beads.

Evolution of Weld Cleanliness

Surface cleanliness standards (i.e., SP-11, SP-10, SP-5, etc.) merely catalog the visual appearance /cleanliness and that one may expect to achieve when specific tools and/or apparatus are properly used for cleaning applications. The actual results that are achieved ultimately depend upon the knowledge, experience, and skill of those performing the task. Consequently, trained users must have a basic understanding of the physical principles that underlie the tools and processes that are being used for surface treatment applications. It is well known for example, that all surface preparation tools and processes have functional requirements that must be understood in order to successfully adapt the tool for removing surface contaminants and exposing unblemished base metal. If, for example, the free stream of grit blast media is masked or impaired from having direct contact with the target surface, cleaning cannot be achieved. Similar reasoning, of course, applies to all media and cleaning processes. In this section, emphasis is placed upon identifying the weld joint *cleaning patterns* that are inherent to the bristle blast process, whereas the degree and classification of cleanliness is left as a separate matter that is assessed by examining a specific weld cleaning application.

Case 1: Tool feed *parallel* to weld bead.

First, weld cleaning performance is evaluated by examining the results that are obtained when the user is aligned perpendicular to the weld, and movement of the tool proceeds along the direction (i.e., *parallel*) to the weld bead. This method of use is readily visualized by referring to the illustration shown in Figure 7, which depicts customary implementation of the bristle blast process. Thus, the surface shown in Figure 19a has been generated by *single pass*, overlapping movement of the tool along the direction of the weld bead and the joined

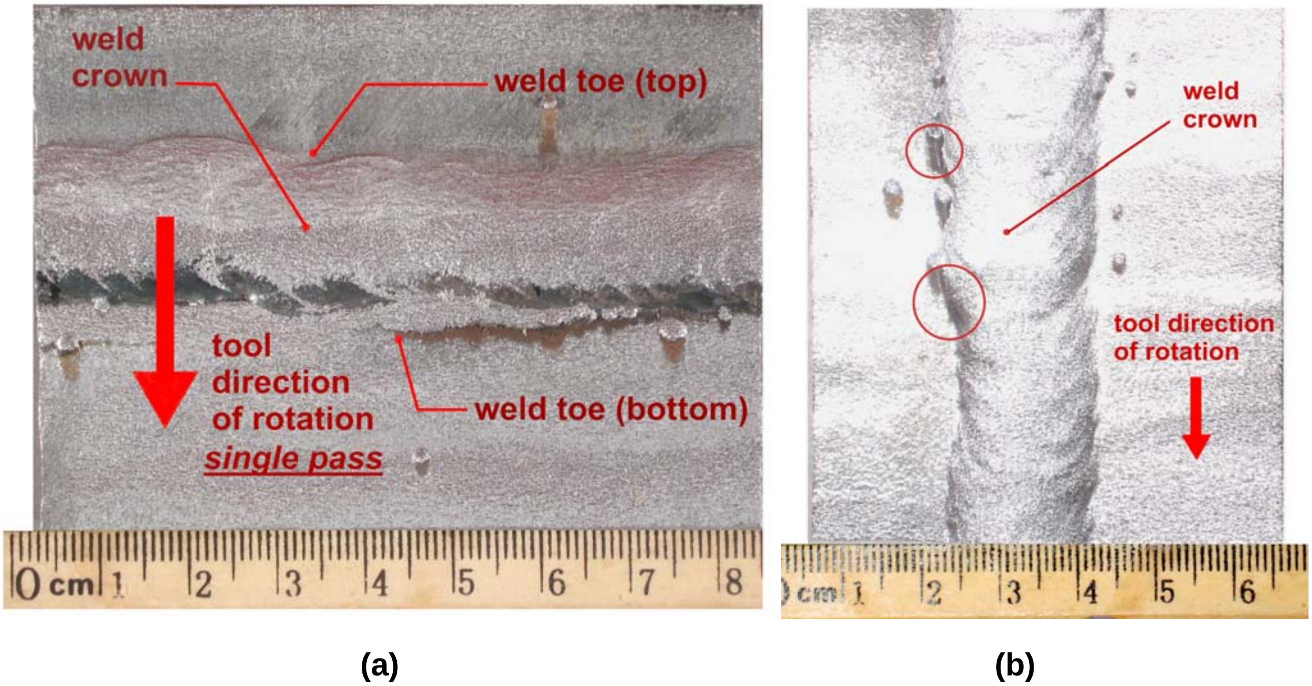


Figure 19 (a) Surface obtained by using single-pass of bristle blasting tool in direction (a) parallel to weld bead, and (b) perpendicular to weld bead.

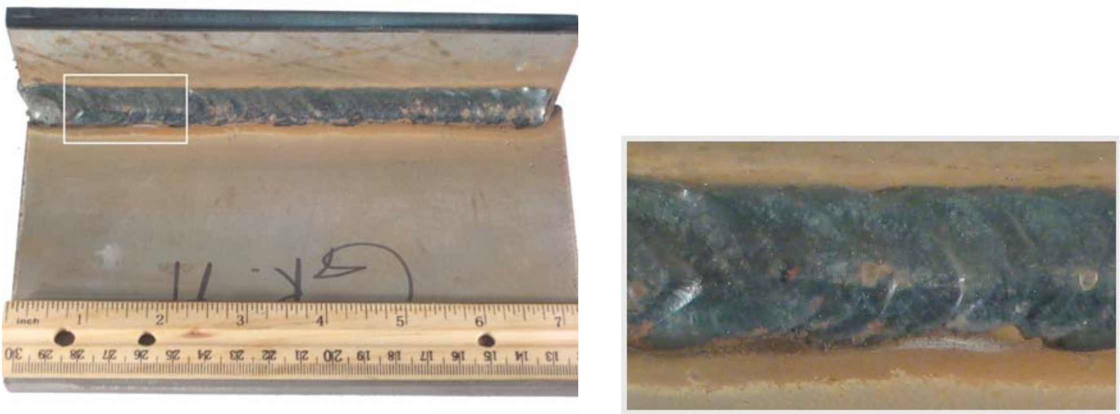
plates. Careful examination of Figure 19a indicates that as bristles strike the surface, wire tips directly impact the top of the weld toe, leading to complete cleaning along this part of the weld seam. Similarly, the crown of the weld bead is both cleaned and textured. However, the bottom of the toe weld shows little or no evidence of bristle tip contact, because this portion of the contact zone is partially masked by the elevated (domed-shaped) weld crown. Nevertheless, it is evident that the lower portion of the weld seam can be cleaned by approaching the weld bead from the opposite direction; that is, a 180 degree reorientation of the tool will promote direct impact of bristle tips with this (lower) portion of the weld seam.

Case 2: Tool feed *perpendicular* to weld bead.

Next, weld cleaning performance is evaluated by examining the results that are obtained when the user applies the tool across (i.e., *perpendicular*) the weld bead. In this case, the tool repeatedly traverses the weld bead, and complete coverage is achieved by sequentially overlapping each previously cleaned portion of the weld. This alternate method has been used to generate the surface shown in Figure 19b, and indicates that both the left and right seams of the weld toe have been fully exposed to the direct impact of bristle tips. That is, when used in this manner, the elevation of the weld crown does not mask/impede contact with either side of the weld toe and, therefore, the overall cleanliness of the weld bead surpasses that shown in Figure 19a. Careful examination of Figure 19b, however, does reveal trace locations (see circled regions) where incomplete cleaning has occurred due to local surface anomalies that partially shield the contact of bristle tips. Consequently, complete and thorough cleaning of the weld can be obtained by, once again, approaching the weld bead from the opposite direction; that is, a 180 degree reorientation of the tool will provide full cleaning coverage of the weld seam.

Case 3: Illustration of thorough weld bead cleaning.

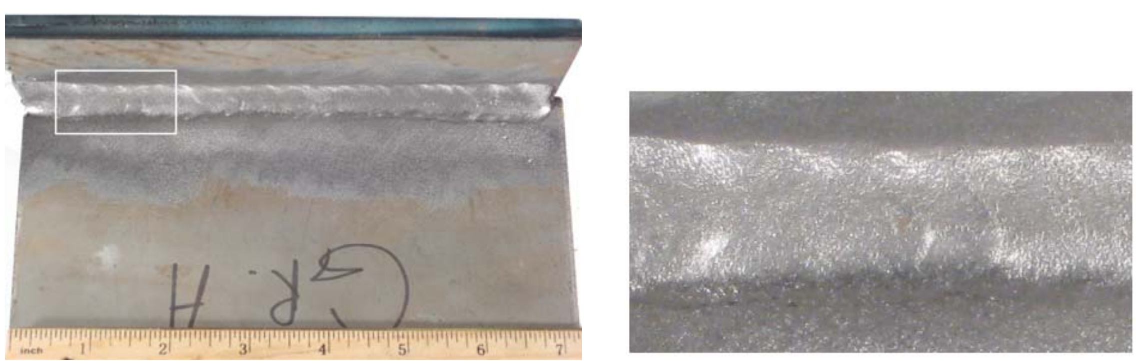
Finally, a formidable application is chosen that illustrates the weld cleaning performance of bristle blasting that can be achieved when following the procedure previously outlined in Case 2. Here, the weld bead is located at the intersection of two plates that are oriented at 90 degrees, which is generally regarded as an application wherein tool access/workspace restrictions are present. Initial condition of the weld bead surface is shown in Figures 20a and



(a) **(b)**

Figure 20 Initial condition of ABS-A plates joined at 90 degrees (a) overall view of weld bead and (b) inset view of weld pool segment.

20b (see inset), which depicts typical spatter and slag that is commonly generated during the formation of welded joints. The procedure that was used for cleaning this weld has been outlined above (see Case 2); that is, the tool has been applied cross-wise (i.e., *perpendicular*) to the weld bead with each pass successively overlapping the previous path. Subsequently, the workpart was inverted (i.e., the tool was reoriented 180 degrees), and the weld bead was again cleaned using previously described methods. The final cleanliness of the overall weld bead is shown in Figure 21a and indicates that complete coverage of the weld joint has been



(a) **(b)**

Figure 21 Weld bead cleaned via bristle blasting process for ABS-A plates joined at 90 degrees (a) overall view of cleaned weld bead and (b) inset view of cleaned weld pool segment.

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achieved. Furthermore, detailed cleanliness of the weld bead (see inset) is magnified and shown in Figure 21b, whereby both the weld crown and weld toe are observed to be completely free of corrosive slag.

SUMMARY AND CONCLUSION

This study has focused on examining the feasibility of using the bristle blast process for simultaneously cleaning and texturing welded joints. Production-quality welded joints were prepared from ABS-A and AH-36 steel, which is commonly used in commercial ship building industries. Metallurgical and mechanical properties of the welded joints were examined, and a series of experiments were carried out on welded specimens to help assess the material removal, profile/texture, and cleanliness performance of the bristle blasting process. Based upon these results, the following conclusions are reached:

a) Hardness of the weld bead can vary by as much as 10-25% when compared with the parent (base metal) steels that are being joined.

b) Removal/abrasion of the ABS-A weld bead proceeds at approximately the same rate as ABS-A base metal, whereas the AH-36 weld bead has a greater propensity for material removal than AH-36 base metal. This latter observation suggests that the weld bead material of AH-36 steel is preferentially abraded when compared to parent material during the surface preparation process.

c) Average roughness profile of bristle blasted welds can vary from R_z=90 μm (as-received tool) to R_z=50 μm (tool having 25 minutes of accrued service).

d) Two distinctly different methods are viable for weld cleaning, namely, parallel and perpendicular tool movement relative to the weld seam.

e) In general, complete and thorough cleaning of the weld is obtained by approaching the weld bead from two different (i.e., mutually opposite) directions.

f) The use of perpendicular (i.e., crosswise) tool movement relative to the weld bead can lead to improved cleaning along the toe weld when compared with parallel tool movement relative to the weld bead; In addition, crosswise movement of the tool may produce near-white metal cleanliness [9] (i.e., SP-10) without the need for reworking the weld bead in the opposite direction.

g) White metal cleanliness [9] (i.e., SP-5) can be achieved along standard flat welds (i.e., butt joint) surfaces as well as along the intersection of two plates that are oriented at 90 degrees.

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