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COMPARATIVE ANALYSIS OF SURFACE PREPARATION TECHNIQUES IN THE MARITIME INDUSTRY FOR CORROSION PROTECTION

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ABSTRACT

This study highlights the importance of abrasive blasting in the maritime industry for ensuring the durability and safety of marine structures. Abrasive blasting is employed to clean and prepare metal surfaces by removing rust, impurities, and old coatings, thereby facilitating optimal adhesion of anti-corrosive coatings that protect against saline corrosion. Eco-friendly abrasives, such as garnet, represent a sustainable alternative, reducing health risks for workers and preventing soil and water contamination. Additionally, classical abrasive blasting is compared to the use of rotary abrasive discs, which allow for more precise cleaning control while minimizing dust and noise.

The analytical methods employed to evaluate the efficiency of the surface preparation process include adhesion testing, roughness measurement, contact angle measurement, and optical microscopy. These techniques enable a detailed assessment of the characteristics of treated surfaces.

KEYWORDS: corrosion, maritime industry, adhesion, roughness, SEM, optical microscopy

1. INTRODUCTION

Abrasive blasting is essential in the maritime industry to ensure the durability and safety of marine structures. This process involves cleaning and preparing the metal surfaces of ships by removing rust, impurities, and old paint layers. In this way, optimal adhesion is achieved for protective coatings, such as anti-corrosion paints, which safeguard against saline corrosion. Additionally, abrasive blasting contributes to maintaining the structural integrity of ships, reducing the risk of damage and enhancing long-term operational efficiency [1].

As highlighted in specialized literature, structures affected by corrosion are significantly more vulnerable to cracks and mechanical failure under pressure from water or cargo, which can lead to major damage and even accidents [2].

The use of eco-friendly abrasives helps protect marine flora and fauna by avoiding contamination of water and soil with heavy metals or other toxins. Furthermore, these materials reduce health risks for workers, as they produce less harmful dust and do not contain hazardous substances. Eco-friendly abrasives also maintain high efficiency in cleaning and preparing metal surfaces, ensuring optimal adhesion for anti-corrosion coatings without compromising the ship's durability or operational performance [3].

Red garnet is frequently used in ship blasting, steel structure construction, and offshore equipment maintenance. Garnet is a non-toxic material that does not generate harmful silica dust, thus improving workers' health and reducing exposure to dangerous substances. Its use enhances working conditions and promotes safety [4].

Being eco-friendly and biodegradable, garnet does not contaminate soil or water during the blasting process or after disposal, making it a sustainable option for industrial maintenance activities [4].

Compared to traditional abrasive blasting, which involves the use of abrasive particles propelled by compressed air, rotary disc abrasion generates less dust and noise, making it more suitable for sensitive environments and confined spaces. Additionally, this method provides greater control over cleaning intensity and treated area, minimizing the risk of damage to the metal substrate. It uses rotary abrasive discs to remove oxide layers, old paint, and other impurities from metal surfaces, leaving a uniform texture that is ready for the application of anti-corrosion protections [5].

Rotary brushes and abrasive discs are versatile tools widely used in various industries and applications [5]. Both classic abrasive blasting and rotary disc abrasion are two surface preparation methods frequently employed in the industry for cleaning, smoothing, and preparing metal substrates before applying anti-corrosion protections or coatings [6].

Polymeric paints are widely used in the maritime industry as anti-corrosion solutions due to their excellent protective properties and durability. These paints are formulated from synthetic polymer resins, such as epoxy, polyurethane, and vinyl, which create a protective layer resistant to specific marine environmental degradation factors, including constant exposure to saltwater, high humidity, UV radiation, and temperature variations [7].

2. MATERIALS AND METHODS

The materials used in the experiments presented in this study include:

2.1. Steels

A common choice for the construction of commercial ships, cargo vessels, ferries, and offshore structures is AH36-grade steel, a high-strength, low-alloy steel.

Table 1. *Chemical composition and carbon equivalent [8]*

C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Cu [%]	Al [%]	Ti [%]	V [%]	Mo [%]	Ni [%]	CEq [%]
0.157	0.392	1.501	0.014	0.003	0.03	0.015	0.042	0.003	0.003	0.08	0.01	0.2763

AH36 is designed to withstand the harsh saline conditions of marine environments, and microalloying technology is used to enhance its performance. Elements such as Nb, V, Ti, and other alloying metals, combined with a controlled rolling process, refine the grain structure and improve hardness. As one of the highest-performing steels produced globally, the H-series steels for shipbuilding are optimized for nearly all mechanical properties. AH36 is almost exclusively used in shipbuilding, marine equipment, offshore oil drilling platforms, and other marine applications [9].

2.2. Abrasive Grit - Red Garnet

For the abrasive material, red garnet was used. This highly durable abrasive has a hardness of 8.0 on the Mohs scale, consisting of angular particles with sharp edges. It is obtained from almandine, a natural rock extracted from mines and subjected to specific processes to ensure excellent performance in cleaning and blasting process [10].

Additionally, red garnet is non-toxic, with a silicate content of less than 0.1%, and does not generate significant amounts of dust during the blasting process, contributing to environmental protection [10].

The composition of red garnet used as an abrasive material for AH36 naval steel is presented in Table 2. The physical and chemical properties of red garnet are shown in Table 3.

Table 2. *Composition of red garnet used as an abrasive material for AH36 naval steel*

Material	[%]
Almandine	98%
Ilmenite	1-2%
Quartz	0.5%
Others	0.5%

Table 3. *Physical and Chemical Properties of the Abrasive Grit for AH36 Naval Steel*

Property	Value
Hardness (Mohs scale)	8.0
Silica content	<0.1%
Specific Gravity	3.9-4.1
Shape	Angular, sharp-edged
Bulk Density	1.4-1.6 g/cm³
Mineral Composition	Almandine
pH	7-8
Water Solubility	Insoluble
Dust Generation	Low

This table provides the typical physical and chemical properties of red garnet as an abrasive grit for use with AH36 naval steel.

2.3. Anti-corrosion Protective Coatings

To protect EH36 naval steel from corrosion, an epoxy primer with a polyamide hardener was chosen, formulated with bisphenol A and epichlorohydrin, manufactured by Akzo Nobel, Germany. This universal light-colored epoxy primer provides excellent abrasion resistance and anti-corrosion protection. The product was supplied in two separate cans, with each component kept in individual containers to preserve the integrity and effectiveness of the composition.

The physical-mechanical characteristics of the Intergard 7600 primer are detailed in Table 1, while its physical-chemical properties are outlined according to the manufacturer's specifications [11]. This information is essential for evaluating the performance and compatibility of the epoxy primer in naval steel surface protection applications, ensuring that the strict standards of the maritime industry are met regarding durability and resistance to aggressive marine environments.

2.4. Sample Preparation

This study evaluates the effectiveness of various surface preparation methods for AH36 steel, commonly used in the maritime industry, prior to th application of anti-corrosion coatings. The samples were made from two sheets of AH36 steel, one prepared using classic abrasive blasting with red garnet (mesh size 0.3-0.6 mm) and the other using mechanical blasting with a rotary abrasive disc.

2.4.1. Mechanical Blasting with Rotary Abrasive Disc

For the mechanical surface preparation, a Metabo pneumatic angle grinder was used, equipped with a 125 mm diameter abrasive disc, with a grit size of 125. The disc was operated at a speed of 15,000 revolutions per minute, and the grinder consumed 0.6 m³ of air per minute at a pressure of 6 kgf/cm².

2.4.2. Classic Abrasive Blasting with Red Garnet

Classic abrasive blasting was carried out using an exterior blasting machine, model Sabiatrice CB215 D-1, with an open jet. The working parameters included a blasting pressure of 7 bar and a nozzle size of 7 mm, using red garnet with mesh sizes of 0.3-0.6 mm.

2.4.3. Application of Anti-corrosion Protective Coating

After surface preparation, all samples were coated with Intershield 300 epoxy primer using an airless spray pump, Wagner Super Finish 23 Pro, designed for epoxy resin-based paints. The working parameters for applying the primer were as follows: operating pressure of 210 bar, paint flow rate of 2 liters/min, and a nozzle diameter of 0.6 mm.

2.4.4. Sample Cutting

Once the paint dried, the steel sheets were cut into 25 x 25 mm square pieces with a thickness of 4 mm for subsequent evaluations.

2.5. Evaluation Methods

The prepared samples were subjected to standardized tests to evaluate the following properties:

Roughness Profile: The evaluation of the treated surface roughness, necessary for proper paint adhesion. The roughness profile of the sample surfaces was assessed bidimensionally using an Insize C200 roughness meter. The measured parameters included Ra, Rq, and Rz.

Adhesion of the Protective Coating: Testing the paint's resistance to determine the degree of adhesion to the metal substrate. The instrument used for determining adhesion using the scratch method was MLSADT 502-6.

Hydrophobicity Degree: Measuring the contact angle to evaluate the surface's ability to repel water, an essential property in marine environments.

Data recording, including the contact angle between the naval steel E32 surfaces, both with and without protective coatings, as well as the analysis of water droplets on these surfaces, was performed using the OCA 15EC goniometer from Dataphysics, Germany.

Optical Microscopy: The analysis of the paint layer structure and its adhesion to the substrate was conducted to identify any defects or discontinuities. For surface morphological studies of AH36 naval steel subjected to eco-friendly grit blasting, abrasive blasting with a rotary disc, as well as AH36 steel coated with primer, the Kern Optics optical microscope was used.

3. RESULTS

Sample Codification

The samples used in this case study were codified as follows:

• The codified sample AH36SGE refers to the eco-friendly grit blasting treatment applied to AH36 steel.

• The codified sample AH36SDA involves mechanical blasting of AH36 steel using abrasive discs.

• The codified sample AH36+GRUND refers to AH36 steel that was subjected to a blasting process followed by the application of an epoxy primer.

As can be seen in Table 4.

Table 4. *Sample Codification*

Sample Code	Description
AH36SGE	AH36 naval steel blasted with eco-friendly grit
AH36SDA	AH36 naval steel blasted with abrasive disc
AH36+GRUND	AH36 naval steel blasted and primed with epoxy primer

3.1. Roughness Evaluation

AH36 SGE, with a roughness of 12.75 micrometers, provides superior adhesion due to its rough texture. However, this increased roughness may lead to higher material consumption and a less aesthetically pleasing appearance.

AH36 SDA, with a roughness of 7.27 micrometers, strikes a balance between adhesion and application efficiency, making it suitable for various applications.

AH36 with Primer offers a uniform surface, ready for the application of a final coating, providing additional benefits in terms of protection and durability.

The selection of the optimal roughness level depends on the specific requirements of the application, considering the trade-offs between adhesion, material consumption, and aesthetic preferences. In Figure 1, the roughness parameters are graphically represented.

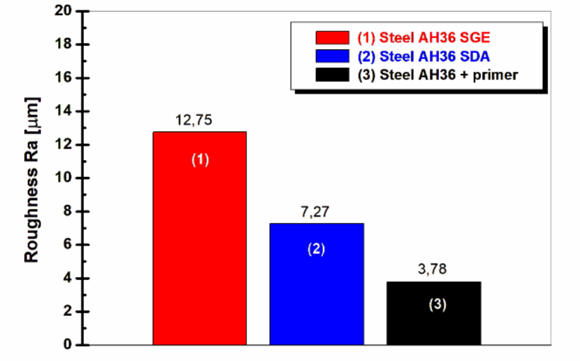

Figure 1. *Roughness Parameters Measured for: a) AH36SGE, b) AH36SDA and c) AH36+primer*

This figure visually represents the roughness parameters measured for each of the surface preparation treatments applied to AH36 steel, showing their comparative values and profiles.

3.2. Preprocessing of 3D Roughness Profiles Using ImageJ1.50i Software and SEM Micrographs

The preprocessing of 3D roughness profiles using ImageJ1.50i software and SEM micrographs provided a comprehensive characterization of the AH36 naval steel surfaces. This method allows for clear visualization of the topography and precise evaluation of roughness parameters, which are essential for understanding the material's behavior and performance in marine applications. The detailed analysis of the surface features contributes significantly to predicting the effectiveness of corrosion protection and the longevity of the material in harsh environmental conditions.

Figure 2. *3D Roughness Profiles for: a) AH36SGE and b) AH36SDA*

This figure displays the 3D roughness profiles of the two treated surfaces, illustratingtheir respective topographies and roughness characteristics, which are essential for assessing their suitability for marine applications.

3.2.1. Adhesion Analysis of the Primer on the AH36 Naval Steel Surface

The evaluation of paint adhesion to steel substrates is crucial for determining the performance and durability of protective coatings. In this study, two types of AH36 steel substrates, each treated with different surface treatment methods, were used to assess the quality of the adhesion of the applied paint layer.

AH36SGE refers to AH36 steel subjected to an ecological blasting process. After applying the primer and conducting the adhesion test, the results indicated an ISO Class 1 and ASTM Class 4B rating. According to the ISO standard, Class 1 representsvery good adhesion, with only a small portion of the paint detaching during the test. In the ASTM standard, Class 4B signifies that less than 5% of the paint has detached from the substrate, suggesting an adequate performance of the coating on the substrate prepared with ecological blasting, as shown in Figure 3.

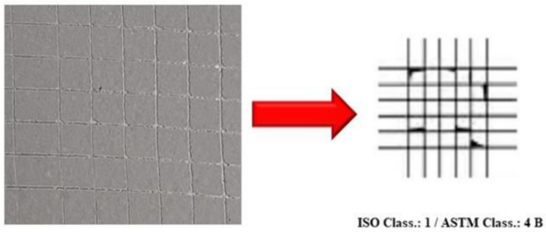

Figure 3. *Adhesion Testing for AH36SGE*

The AH36SDA sample represents AH36 steel prepared through mechanical blasting using an abrasive disc. The adhesion test conducted on this substrate indicated an ISO class 0 and an ASTM class 5B. An ISO class 0 denotes exceptional adhesion, with no paint detachment observed after the test (Figure 4). According to the ASTM standard, class 5B indicates that no paint loss was observed, highlighting optimal adhesion and effective surface preparation through mechanical blasting.

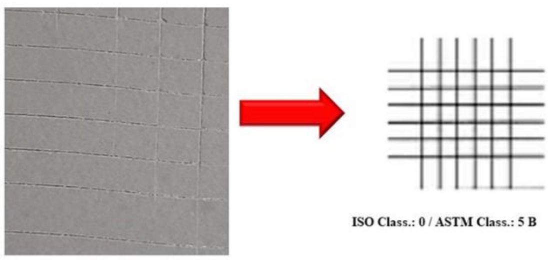

Figure 4. *Adhesion Testing for AH36 Marine Steel, AH36SDA Sample*

The results obtained from the adhesion testing of the paint layer on the AH36SGE and AH36SDA substrates highlight the differences in the performance of the surface preparation methods. Although both methods demonstrated good adhesion, mechanical blasting with an abrasive disc (AH36SDA) yielded superior results, as indicated by ISO class 0 and ASTM class 5B. This suggests that mechanical blasting may offer better surface preparation for the application of protective coatings, ensuring maximum paint adhesion and, consequently, improved coating durability.

3.2.2. Analysis of Scanning Electron Microscopy (SEM)

The SEM images of the surface blasted with eco-friendly grit reveal a uniform and consistent texture, with regularly distributed peaks and valleys. The surface exhibits even roughness, ensuring good adhesion for the protective layer. High roughness is essential for securing paints and other protective coatings, preventing detachment in harsh marine environments. Eco-friendly grit blasting effectively removed all traces of rust and impurities, leaving a clean surface ready for further treatments. The uniform texture, ideal for subsequent applications of paints or other protective layers, is clearly visible.

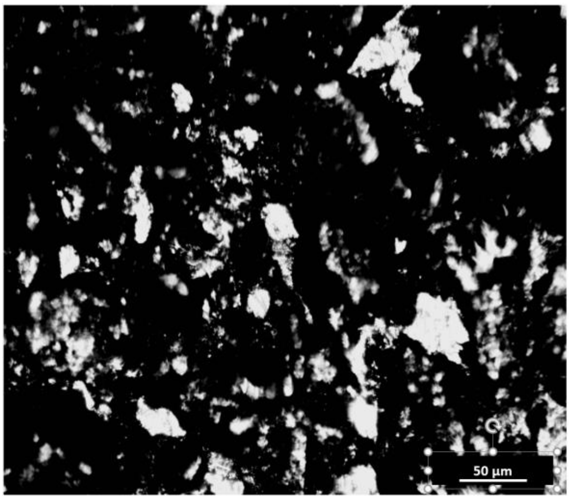

Figure 5. *Optical Microscope Image at 50 µm Magnification for AH36SDE*

The SEM images of the surface blasted with an abrasive disc show a more irregular texture, with peaks and valleys distributed unevenly. The surface exhibits variable roughness, which could result in uneven adhesion of the protective layers. Areas with lower roughness may allow water and other corrosive agents to infiltrate, reducing the effectiveness of the protection. Although abrasive disc blasting removes most impurities, some particles or traces of oxidation may remain in the deeper areas of the texture.

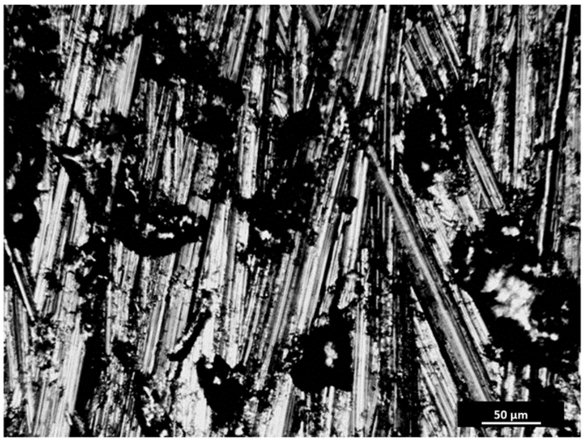

Figura 6. *Optical Microscope Image at 50 µm Magnification for AH36SDA*

4. CONCLUSIONS

Eco-friendly grit blasting is more effective in creating a uniform and clean surface, ensuring consistent roughness that improves the adhesion of protective layers. This makes it ideal for applications where durability and the effectiveness of corrosion protection are critical.

On the other hand, abrasive disc blasting is fast and economical, but it can produce a surface with variable roughness and residual impurities, which may negatively affect the performance of the applied protection.

Eco-friendly grit blasting created a surface with uniform and consistent roughness, which is essential for ensuring good adhesion of protective layers. In contrast, abrasive disc blasting produced more variable roughness.

Eco-friendly grit blasting effectively removed all impurities and oxides, leaving a clean surface. Abrasive disc blasting, although effective, may leave traces of impurities in the deeper areas of the texture.

Surfaces blasted with eco-friendly grit exhibit better adhesion of protective layers due to the uniform and consistent texture. The variable roughness from abrasive disc blasting may compromise adhesion in certain areas.

For critical applications in marine environments, where long-term corrosion protection is essential, eco-friendly grit blasting is preferred due to its benefits in terms of adhesion and durability of protective layers.

REFERENCES

1. **Zulkarnain, I.; Mohamad Kassim, N.A.; Syakir, M.I.; Abdul Rahman, A.; Md Yusuff, M.S.; Mohd Yusop, R.; Keat, N.O.,** *Sustainability-Based Characteristics of Abrasives in Blasting Industry.* Sustainability 2021, 13, 8130. https://doi.org/10.3390/su13158130

2. **Nair, A., Sivaprasad, K., & Nandakumar, C. G.,** C*rack assessment criteria for ship hull structure based on ship operational life.* Cogent Engineering, 4(1), 2017, https://doi.org/10.1080/23311916.2017.1345044

3. Kılınç, İ., Budakçı, M., and Korkmaz, M, *The use of environmentally friendly abrasive blasting media for paint removal from wood surfaces,* BioResources 18(1), 2023, Pages 1185-1205, http://dx.doi.org/10.15376/biores.18.1.1185-1205

4. Bogatu, N., Muresan, A.C., Mardare, L., Ghisman, V., Ravoiu, A., Dima, F.M., Buruiana, D.L. *The Influence of Different Type Materials of Grit Blasting on the Corrosion Resistance of S235JR Carbon Steel*. Inventions 2023, 8, 39. https:// doi.org/10.3390/inventions8010039

5. Korga S, Żyła K, Józwik J. *Analysis of the Abrasive-Type Influence on the Effectiveness of Rotary Cleaning of Machine Parts with Complex Geometric Features*. Materials. 2020; 13(22):5144. https://doi.org/10.3390/ma13225144

6. Fernandez, I.; Lundgren, K.; Zandi, K. *Evaluation of corrosion level of naturally corroded bars using different cleaning methods, computed tomography, and 3D optical scanning*. Mater. Struct. 2018, 51, 51–78.

7. Jozwik J, Dziedzic K, Barszcz M, Pashechko M. *Analysis and Comparative Assessment of Basic Tribological Properties of Selected Polymer Composites*. Materials. 2020; 13(1):75. https://doi.org/10.3390/ma13010075

8. Pastorcica, D., Vukelicb, G. Bozic, Z.,, *Numerical model of corrosion influence on mechanical behavior of steel AH36*, Procedia Structural Integrity 42 (2022) 374–38, https://creativecommons.org/licenses/by-nc-nd/4.0

9. https://www.metalsusa.com/ah36-grade-steel/

10. Klimpel, F., Bau, M. & Graupner, T. *Potential of garnet sand as an unconventional resource of the critical high-technology metals scandium and rare earth elements*. Sci Rep 11, 5306 (2021). https://doi.org/10.1038/s41598-021-84614-x

11. https://marinecoatings.brand.akzonobel.com/m/ 48745a6c2eae3195/original/KUA766_0010eu_UA_EN_20170507_ 1.pdf7.