ENVIRONMENTAL IMPACT ASSESSMENT OF ABRASIVE MATERIALS IN INDUSTRIAL BLASTING PROCESS

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by

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I dedicate this thesis to all of you.

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LIST OF SYMBOLS

%	Percentage
ρ_A	Apparent density
ρ_w	Density of water at the temperature of the determination
µm	Micrometer
CF	Characterization factors
M	Moisture content
mm	Millimeter
m/m	Mass/mass
R_a	Average roughness of a surface
R_z	Profile peak-to-valley height
V	Volume of silver nitrate solution used
w(Cl)	Water-soluble chloride content

LIST OF ABBREVIATIONS

3D	3-dimensional
ADP	Abiotic depletion potential
Al_2O_3	Aluminum oxide
AP	Acidification potential
BaO	Barium oxide
CaO	Calcium oxide
Cl	Chlorides
CML	Centre of Environmental Science Leiden
CO_{2e}	Carbon dioxide equivalents
Co_3O_4	Cobalt oxide
Cr_2O_3	Chromium (III) oxide
CuO	Copper (II) oxide
DOE	Department of Environment
DOSH	Department of Occupational Safety and Health
EP	Eutrophication potential
$FAETP_{20years}$	Freshwater aquatic ecotoxicity potential within 20 years
$FAETP_{inf}$	Freshwater aquatic ecotoxicity potential within infinity
Fe_2O_3	Iron oxide
$FSETP_{20years}$	Freshwater sediment ecotoxicity potential within 20 years
$FSETP_{inf}$	Freshwater sediment ecotoxicity potential within infinity
GHG	Greenhouse gas
GWP	Global Warming Potentials

GWP_{500}	Global Warming Potentials within 500 years
$HTP_{20years}$	Human toxicity potential within 20 years
HTP_{inf}	Human toxicity potential within infinity
ISO	International Organization for Standardization
K_2O	Potassium oxide
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
$MAETP_{20years}$	Marine aquatic ecotoxicity potential within 20 years
$MAETP_{inf}$	Marine aquatic ecotoxicity potential within infinity
MgO	Magnesium oxide
MnO	Manganese (II) oxide
$MSETP_{20years}$	Marine sediment ecotoxicity potential within 20 years
$MSETP_{inf}$	Marine sediment ecotoxicity potential within infinity
N/A	Not available
Na_2O	Sodium oxide
Nb_2O_5	Niobium pentoxide
ND	Non-detectable
NiO	Nickel (II) oxide
NIOSH	National Institute of Occupational Safety and Health
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
ODP	Ozone depletion potential
OSHA	Occupational Safety and Health Administration

PbO	Lead (II) oxide
P_2O_5	Phosphorus pentoxide
POCP	Photochemical ozone creation potential
PPE	Personal protective equipment
PTS	Petronas Technical Specifications
Rb_2O	Rubidium oxide
RCS	Respirable crystalline silica
REL	Recommended exposure limit
Sa	Surface cleanliness level
SDGs	Sustainable Development Goals
SEM	Scanning electron microscopy
SiC	Silicon carbide
SiO_2	Silica
SO_3	Sulfur trioxide
SrO	Strontium oxide
STS	Shell Technical Specifications
TCLP	Toxicity Characteristic Leaching Procedure
$TETP_{20years}$	Terrestrial ecotoxicity potential within 20 years
$TETP_{inf}$	Terrestrial ecotoxicity potential within infinity
TiO_2	Titanium dioxide
TWA	Time-weighted average
USEPA	United States Environmental Protection Agency
UV-B	Ultraviolet B
V_2O_5	Vanadium (V) oxide

VOCs	Volatile organic compounds
WO_3	Tungsten (VI) oxide
XRF	X-ray Fluorescence
XRD	X-ray Diffraction
Y_2O_3	Yttrium (III) oxide
Y-TZP	Yttrium-stabilized tetragonal zirconia
ZnO	Zinc oxide
ZrO_2	Zirconium dioxide
Zr_2O_3	Zirconium oxide-based
μ-EDXRF	Micro-energy dispersive X-ray fluorescence

PENILAIAN KESAN ALAM SEKITAR TERHADAP BAHAN LELASAN DALAM PROSES PEMBAGASAN INDUSTRI

ABSTRAK

Kajian kesan alam sekitar terhadap bahan pembagasan dalam industri pembagasan adalah usaha penyelidikan yang penting. Pembagasan, digunakan secara meluas dalam industri penyediaan permukaan dan pengecatan, melibatkan penumpuan bahan pembagasan tekanan tinggi ke permukaan. Penyelidikan ini bertujuan untuk mencirikan pelbagai bahan pembagasan dan menilai kesan alam sekitar mereka. Pelbagai bahan pembagasan yang dicadangkan, termasuk berlian, garnet, jadecut, seramik, dan dua jenis kaca (kaca Duragrit dan Kaca pembagasan), menjalani penilaian teliti komposisi dan kehabluran sebatian mereka, menggunakan sinar-X pendarfluor (XRF) dan sinar-X analisis pembelauan (XRD). Kedua-dua kaca Duragrit dan Kaca pembagasan muncul sebagai calon yang menjanjikan, memaparkan struktur amorfus dan memenuhi keperluan Jabatan Keselamatan dan Kesihatan Pekerjaan (DOSH) untuk pembagasan terbuka. Sifat mekanikal bahan ini dicirikan secara menyeluruh, termasuk penyerakan saiz zarah (ISO11127-2), ketumpatan ketara (ISO11127-3), kekerasan (ISO11127-4), kandungan lembapan (ISO11127-5), dan klorida larut air (ISO11127- 7). Ketumpatan ketara mengukur 2.17×10^3 kg/m^3 untuk kaca Duragrit dan 2.5×10^3 kg/m^3 untuk Kaca pembagasan, dengan kandungan lembapan pada 0.01%. Klorida larut air adalah “Nil” untuk kaca Duragrit dan 0.0001% untuk Kaca pembagasan. Penemuan ini adalah asas untuk pembersihan pembagasan yang berkesan, memastikan pematuhan keselamatan, dan memelihara ciri permukaan yang diingini. Keberkesanan kaca Duragrit dan Kaca pembagasan dalam penyediaan

permukaan mematuhi piawaian industri, memenuhi keperluan Spesifikasi Teknikal Petronas (PTS) dan Spesifikasi Teknikal Shell (STS). Penilaian meliputi kebersihan permukaan pada panel permukaan yang dibagaskan, mengesahkan kesesuaian untuk kegunaan praktikal. Mematuhi piawaian seperti ISO 8501-1, ISO 8502 Bahagian 3, 6, dan 9, dan ISO 8503 untuk penilaian penyediaan permukaan (ISO 8504-2), kebersihan permukaan yang dicapai Sa2.5 dengan paras habuk 2, garam-bahan cemar larut berukuran 18.16 mg/m^2 dan 21.96 mg/m^2, kekonduksian permukaan 2.27 µS/cm dan 9.9 µS/cm, dan profil permukaan 90 µm dan 75 µm, masing-masing untuk kaca Duragrit dan Kaca pembagasan. Selain itu, penilaian tahap ketoksikan bahan dalam sisa selepas pembagasan dijalankan, dengan mengambil kira aspek alam sekitar dan kesan kitaran hayat kaca Duragrit dan Kaca pembagasan. Penilaian ini selaras dengan piawaian pengurusan bahan sisa Jabatan Alam Sekitar (DOE), meletakkan penyelidikan di barisan hadapan kemajuan dalam industri pembagasan. Kesimpulanya, bahan yang dikenal pasti (kaca Duragrit dan Kaca pembagasan) muncul sebagai calon alternatif untuk operasi pembagasan, terutamanya untuk tujuan pembagasan terbuka, memandangkan ciri-ciri mesra alam dan pematuhan piawaian keselamatan, sekali gus menawarkan jalan yang menjanjikan proses pembagasan yang lebih selamat, berkesan dan mementingkan alam sekitar.

ENVIRONMENTAL IMPACT ASSESSMENT OF ABRASIVE MATERIALS IN INDUSTRIAL BLASTING PROCESS

ABSTRACT

The environmental impact study of abrasive materials in the blasting industry is a pivotal research endeavour. Abrasive blasting, widely used in surface preparation and painting industries, involves projecting high-pressure abrasive material onto surfaces. This research aims to characterize various abrasive materials and assess their environmental impact. Various proposed abrasive materials, including diamond, garnet, jadecut, ceramic, and two types of glass (Duragrit glass and Glass blast), undergo a meticulous examination of their compound composition and crystallinity, utilizing X-ray Fluorescence (XRF) and X-ray diffraction (XRD) analyses. Both Duragrit glass and Glass blast emerge as promising candidates, displaying an amorphous structure and meeting the Department of Occupational Safety and Health (DOSH) requirements for open blasting. Mechanical properties of these materials are thoroughly characterized, including particle size distribution (ISO11127-2), apparent density (ISO11127-3), hardness (ISO11127-4), moisture content (ISO11127-5), and water-soluble chlorides (ISO11127-7). For instance, apparent density measures 2.17×10^3 kg/m^3 for Duragrit glass and 2.5×10^3 kg/m^3 for Glass blast, with moisture content at 0.01%. Water-soluble chlorides are Nil for Duragrit glass and 0.0001% for Glass blast. These findings are foundational for effective abrasive blast-cleaning, ensuring safety compliance, and preserving desired surface features. The efficacy of Duragrit glass and Glass blast in surface preparation adheres to industry standards, meeting Petronas Technical Specifications (PTS) and Shell Technical Specifications (STS)

requirements. The assessment extends to surface cleanliness on the blasted surface panel, confirming suitability for practical use. Adhering to standards such as ISO 8501-1, ISO 8502 Part 3, 6, and 9, and ISO 8503 for surface preparation assessments (ISO 8504-2), the achieved surface cleanliness Sa2.5 with a dust level of 2, salt-soluble contaminants measuring 18.16 mg/m^2 and 21.96 mg/m^2, surface conductivity of 2.27 µS/cm and 9.9 µS/cm, and surface profiles of 90 µm and 75 µm, for Duragrit glass and Glass blast, respectively. Additionally, an assessment of the toxicity level of substances in post-blasting residues is conducted, considering environmental aspects and the lifecycle impact of Duragrit glass and Glass blast. This evaluation aligns with Department of Environment (DOE) waste management standards, positioning the research at the forefront of advancements in the blasting industry. In summary, the identified materials (Duragrit glass and Glass blast) emerge as alternative candidates for blasting operations, particularly for open-blasting purposes, given their environmentally friendly characteristics and compliance with safety standards, thus offering a promising avenue for safer, more effective, and environmentally conscious abrasive processes.

CHAPTER 1

INTRODUCTION

1.1 Background of study

The environmental impact study of abrasive media in the blasting industry is a critical and multifaceted research area. Abrasive blasting, recognized as a technique for violently projecting a high-pressure stream of abrasive material onto surfaces, is extensively used in industries such as shipbuilding, automotive, and surface-preparation and painting. Common abrasive materials include garnet, sand, synthetic abrasives, mineral abrasives, metallic abrasives, coal slags, and smelter slags. Since the 1920s, abrasive blasting has been acknowledged as one of the most dangerous and hazardous operations, posing risks such as potential exposure to airborne crystalline silica, a known occupational hazard (Madl et al., 2010).

Workers engaged in abrasive blasting face risks of exposure to respirable crystalline silica, contributing to the development of conditions such as silicosis. According to the Centers for Disease Control and Prevention, approximately 2 million US workers may have been exposed to respirable crystalline silica between 2001 and 2010, heightening the urgency to address safety concerns in this industry (Bang et al., 2015; Madl et al., 2008). The recommended exposure limit (REL) for respirable crystalline silica is 0.05 mg/m^3 as a time-weighted average (TWA) concentration for up to a 10-hour workday (NIOSH Hazard Rev., 2002). The inherent risks, including exposure to loud noises and the generation of significant dust, emphasize the need for effective safety measures.

This research seeks to bridge the existing knowledge gap surrounding the environmental implications of abrasive media in the blasting industry. The choice of abrasive media introduces a range of environmental challenges, from water contamination due to runoff from blasting sites to habitat disruption and potential threats to human health. Considering global efforts toward environmental sustainability, regulatory bodies tightening standards, and the industry facing pressure to adopt eco-friendly practices, understanding the environmental impact of abrasive media becomes paramount. This study explores issues such as abiotic resource depletion, human toxicity, ecotoxicity, and others aiming to contribute valuable insights to industry practices and regulatory frameworks.

Abiotic resource depletion underscores the industry's heavy reliance on finite minerals and metals for abrasive media production. The accelerated depletion of these resources raises profound concerns about resource sustainability, energy consumption, and environmental degradation, necessitating a holistic examination to inform sustainable resource management practices. Human toxicity, as one of the major concerns, emphasizes the potential health risks faced by workers exposed to hazardous substances within abrasive media. Assessing human toxicity is crucial for prioritizing worker safety and well-being, requiring an unflinching evaluation of potential health effects and the development of protective measures.

Meanwhile, recognizing the ecotoxicity potential of abrasive media is imperative, as the release of contaminants into freshwater, marine and terrestrial environments pose a substantial threat to aquatic life and ecosystem integrity. Comprehensive assessments are vital to accurately measure the true extent of this ecotoxic impact and to formulate effective mitigation strategies, ensuring the protection of critical freshwater, marine and terrestrial environments.

In summary, this study is essential for comprehensively addressing concerns related to the environmental impact of abrasive media in the blasting industry. By investigating these concerns, the research aims to provide holistic insights into environmental sustainability and occupational safety, empowering industry stakeholders and policymakers to make informed decisions aligned with environmental stewardship and worker well-being. The research aligns with the Sustainable Development Goals (SDGs) as shown in Figure 1.1 and aims to identify and explore potential characteristics of blasting media as an alternative to free silica content abrasives for blasting activities.

Figure 1.1: Related Sustainable Development Goals (SDGs) that become the key motivating factors to determine the characteristics of green abrasives that contribute to safety; environment and sustainability of the blasting industry (Zulkarnain et al., 2021).

1.2 Problem statement

In recent years, the global imperative for environmental sustainability has intensified, prompting a critical re-evaluation of industrial practices, notably within the abrasive blasting industry - a longstanding pillar in construction, manufacturing, and mining. This industry, central to numerous vital activities, faces escalating scrutiny due to concerns over its potential environmental impact. At the heart of this multifaceted industry lies the discerning selection and utilization of abrasive media, a decision wielding significant influence over the ensuing environmental ramifications of the blasting process.

Foremost among the four major concerns that demands immediate attention is the specter of "Abiotic Resource Depletion." The abrasive blasting industry leans heavily on abiotic resources, namely minerals and metals, in the production of abrasive media. These resources, finite and non-renewable, are essential components in the industry's operations. The act of extracting and consuming these precious materials for abrasive media manufacture raises profound concerns regarding resource depletion. When undertaken at rates that surpass natural replenishment processes, the result is an accelerated depletion of these invaluable resources. The implications are far-reaching, encompassing potential repercussions not only for the industry's future access to these materials but also for increased energy consumption and environmental degradation associated with resource extraction. A holistic examination of abiotic resource depletion is indispensable, encompassing the entire lifecycle of abrasive media, from extraction to eventual disposal (Imtiaz et al., 2021; Aristin et al., 2020).

The second pivotal concern a matter of utmost gravity, is the potential for "Human Toxicity." Workers employed in the abrasive blasting industry find themselves at the forefront of potential exposure to hazardous substances that may reside within abrasive media. These substances, ranging from heavy metals to crystalline silica, carry the ominous potential to wreak havoc on human health. Whether through inhalation or dermal contact, exposure to these toxic components can lead to a litany of adverse health effects, including but not limited to respiratory diseases, skin disorders, and even the insidious specter of cancer. The safety and well-being of workers should remain paramount, and an unflinching assessment of the potential for human toxicity is an indispensable component of this study (Zakaria et al., 2019a; Sambharia & Mali, 2017).

The third dimension of concern guiding this study is the issue of "Ecotoxicity Potential." Abrasive blasting operations intrinsically release abrasive media into the environment, potentially harbouring chemicals or heavy metals that pose a looming threat to freshwater, marine and terrestrial ecosystems (Nasser et al., 2019). The runoff from blasting sites, carrying a mixture of contaminants, holds the inadvertent potential to channel pollutants into the delicate waterways of rivers, lakes, and other aquatic habitats, including sediments (Alaux et al., 2022). The consequences are potentially catastrophic, with aquatic life and sediments susceptible to toxic exposure, putting entire ecosystems at risk of ecological disruption. To achieve environmental sustainability, a comprehensive assessment of the ecotoxicity potential of abrasive media is indispensable. Only through such assessments can the true extent of their impact on freshwater, marine and terrestrial environments be understood, thereby paving the way for mitigation strategies aimed at safeguarding these critical ecosystems (Qu et al., 2016).

The other major environmental concern, including climate change, ozone depletion, photon-oxidant formation, acidification, and eutrophication, are critical in evaluating the overall impact of abrasive blasting operations on the environment and human health. The reduction of greenhouse gas (GHG) emissions is a significant consideration in the context of climate change. The type of abrasives used in blasting operations plays a crucial role in determining waste generation and emission potentials, thereby influencing the overall carbon footprint of the process (Zulkarnain et al., 2021). Additionally, the selection of environmentally friendly abrasives, such as agricultural and glass-based abrasives, can contribute to mitigating the environmental impact of blasting operations. Furthermore, the environmental implications of abrasive media extend to issues of photon-oxidant formation, acidification, and eutrophication. Dry-ice blasting, for example, can induce acid environments, while certain abrasive blasting methods, such as IBIX, may cause dust emission during the projection, potentially contributing to photon-oxidant formation and eutrophication (Pozo-Antonio et al., 2018). These environmental concerns highlight the need for a comprehensive assessment of the ecological impact of abrasive media to develop effective mitigation strategies. In addition to heavy metal pollution and worker safety, the environmental impact of abrasive media in the blasting industry encompasses a wide range of ecological and environmental challenges. Addressing these concerns is vital for promoting sustainable practices and minimizing adverse effects on the environment (Yawson et al., 2020).

Thus, this research seeks to articulate the pressing need for an exhaustive environmental impact study delving into the realm of abrasive media within the abrasive blasting industry. It is a quest to unravel the intricate interplay between abrasive media and the environment, with an unwavering focus on the four major concerns that encompass freshwater aquatic ecotoxicity potential, abiotic resource depletion, land use, and human toxicity. By undertaking this multifaceted exploration, this research is expected to provide holistic insights into the environmental sustainability and occupational safety within the abrasive blasting industry. Armed with this knowledge, industry stakeholders and policymakers can chart a course towards responsible practices and informed decisions that resonate with the principles of environmental stewardship and worker well-being in a rapidly evolving world.

1.3 Research objectives

The objectives of this research are:

i. To examine the compound composition and crystallinity of abrasive materials (diamond, garnet, jadecut, ceramic and 2 types of glass) using XRF and XRD to determine for the most suitable one.

ii. To characterize the mechanical properties of the chosen abrasive materials according to ISO standards guidelines.

iii. To evaluate the surface cleanliness of the blasted surface panel for the effective surface preparation using the surface profile method.

iv. To assess the toxicity level of substances in the blasted residues concerning environmental aspect and the lifecycle impact of the chosen abrasive materials using the LCIA model.

1.4 Scope of study

This research undertakes a comprehensive assessment of abrasive material properties and their environmental implications in the blasting industry. The investigation encompasses a thorough characterization of various abrasive material types (diamond, garnet, jadecut, ceramic, and glass), focusing on properties such as compound composition and crystallinity. The study evaluates environmental aspects and impacts throughout the lifecycle of abrasive material, taking into account their crystalline structure. The study of mechanical property of chosen abrasive material covers the analysis of particle size distribution, apparent density, hardness, moisture content and water-soluble chlorides. Wet abrasive blasting procedures using the chosen abrasive material are executed for blast-cleaning operations. Post-blasting assessment on the treated panel's surface includes analysis of surface cleanliness and roughness. Furthermore, the research delves into the effectiveness of the chosen abrasive material in achieving specific surface preparation and material removal goals, while also considering safety and health implications for workers. In addition to utilizing the United States Environmental Protection Agency (USEPA) method, specifically Toxicity Characteristic Leaching Procedure (TCLP) analysis is used to determine the toxicity of the blasted residues. Ultimately, the study aims to provide recommendations and mitigation strategies to foster environmentally sustainable practices within the industry and contribute valuable insights to the broader understanding of abrasive media's environmental impact.

1.5 Outline of this research

The thesis consists of five chapters. Chapter 1 addresses the background of the study, problem statement, research objectives, the scope of the study, and outlines of this research. Chapter 2 presents a comprehensive review of relevant literature. In Chapter 3, the research methodology is detailed, while Chapter 4 provides an in-depth discussion of the results and findings. Lastly, Chapter 5 offers a summary of the study's findings and provides recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses about the abrasive blasting industry, including its basic principles, problems, and potentials/possibilities. Additionally, the panel substrate and materials used in the abrasive blasting industry will be reviewed. The application, assessment and the environmental impact of this blasting industry will be next covered.

2.2 Abrasive blasting industry

Abrasive blasting, depicted in Figure 2.1 is a general term which is used to describe the act of propelling very fine bits of material at a high velocity. This process is used for cleaning or etching the surface before the treatment of the surface, prior to powder coating, painting, or spray galvanization. Substrates are required to be sandblasted according to their surface conditions. The use of diverse blasting materials creates various types of surface results, increases longevity of the coat. Abrasive blasting leaves an anchor pattern on the material to improve adhesion (Wohltmann et al., 2020).

Figure 2.1: Abrasive blasting operation (Abrasive blasting: Know the hazards, 2017).

The purpose of abrasive blasting is to get rid of any grease, oil, or scale that is already on the surface (Czepułkowska-Pawlak, et al., 2020). Additionally, this method offers a surface that makes it simple for paint to adhere to it. It is also the simplest and quickest technique to remove rust and peeling paint from metal surfaces. Additionally, it is helpful for cleaning those hard-to-reach surfaces.

Generally, abrasive blasting consists of two basic steps: (i) putting the abrasives into the blasting pot and applying pressurised air through the nozzle to the surface to be sandblasted; and (ii) using the nozzle to manage pressure and velocity to help create a trajectory for the blast (Draganovská et al., 2018; Kim et al., 2021; Baglioni et al., 2021).

2.2.1 Basic principles of abrasive blasting

Abrasive blasting has a wide range of applications. Three common uses of abrasive blasting include: (i) surface preparation, (ii) surface finishing, and (iii) surface hardening, across various industries. The process involves propelling fine material bits at high velocity to clean or etch surfaces before treatment, such as powder coating, painting, or spray galvanization. The choice of blasting materials results in various surface finishes, enhancing the longevity of the coat and leaving an anchor pattern on the material to improve adhesion (Poon et al., 2018; Liss & Martynyuk, 2023; Maida et al., 2015).

2.2.1(a) Surface preparation

Surface preparation is a crucial step in treating materials before coating application, adhesive use, and other procedures, particularly in the context of steel and other substrates. This process, often known as blast cleaning, involves abrasive blasting to clear steel surfaces of old coatings, corrosion, and contaminants. In the case of new steel, it removes mill scale accumulated during manufacturing, ensuring the desired level of surface cleanliness. The most typical procedure for new construction based on abrasive blasting is depicted in Figure 2.2.

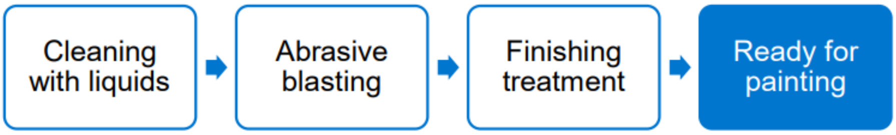

Figure 2.2: The most typical procedure for new construction based on abrasive blasting (Technical guide: Surface preparation, 2020).

Coating manufacturers specify precise profiles for the application of their products. Figure 2.3 illustrates the principle of a roughness profile, often measured by the R_z value. This value, as mentioned in Hempel's Product Data Sheets, represents the average of maximum peaks and depths within the same sampling length. The roughness profile is graded using the Grit or Shot comparator, aligning with paint standard specifications (ISO 8503-2:2000) (Technical guide: Surface preparation, 2020). Table 2.1 provides an overview of primary roughness grades.

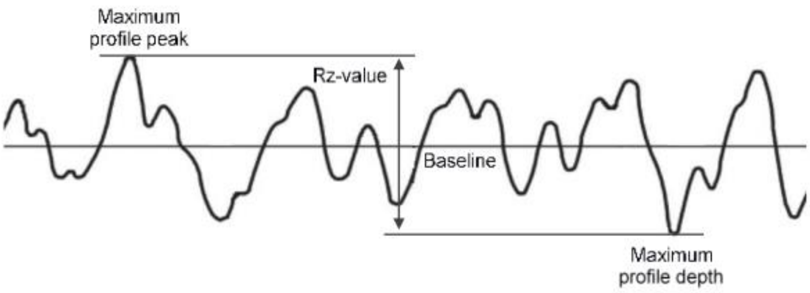

Figure 2.3: The roughness profile as described by R_z-value (Technical guide: Surface preparation, 2020).

Table 2.1: Roughness grades according to ISO 8503-2:2000 (Technical guide: Surface preparation, 2020).

Roughness profile	Rz (µm) Grit comparator	Rz (µm) Shot comparator
Finer than fine	< 20	< 20
Fine	20 - < 50	20 - < 40
Medium	50 - < 90	40 - < 80
Coarse	90 - < 130	80 - < 110
Coarser than coarse	> 130	> 110

Surface preparation serves as a critical precursor to paint coating, ensuring optimal adhesion to the material being protected (Modesto & Mainier, 2023). Abrasive blasting is widely employed for removing rust, peeling paint, and contaminants, creating a clean and roughened surface that significantly enhances coating adhesion (Soja et al., 2020; Zulkarnain et al., 2021). This process modifies the surface state of pre-treated materials, addressing surface irregularities crucial for achieving optimal adhesion and coating performance (Draganovská et al., 2018; Pratikno et al., 2021).

2.2.1(b) Surface finishing

Surface finishing, distinct from surface preparation, focuses on enhancing the usability and appearance of a product through abrasive blasting. This industrial process targets non-ferrous materials like stainless steel, plastic, wood, aluminum, glass, and composite materials. Unlike surface preparation, which readies an object for coating, surface finishing encompasses a variety of processes aimed at altering an object's surface. These processes may improve appearance or impart specific properties such as wear resistance, adhesion, electrical conductivity, and more.

In its most basic form, surface finishing involves removing unwanted residues left from previous processes, such as welding residues, burrs, and imperfections. Depending on the application, it can also involve removing small pieces of unwanted material, ensuring the safety of the finished product. While industrial components may prioritize function over aesthetics, commercial and consumer applications often value aesthetically pleasing finishes as an added benefit.

Various types of finishes exist, some patented and protected, while others are substrate specific. Categories of specialty finishes include ground, burnished, brushed, dull polished, satin polished, bright polished, patterned, corrugated, matte finish, blasted, and peening. Aesthetic surface finishes can be achieved using abrasive blasting techniques. For instance, the Wet Blast technique, incorporating water into the media mix, is used to produce a brushed or polished finish on electronics and consumer goods.

Shot blasting techniques with glass beads or steel shot can impart a hammered finish or peen an object. The glass finishing process utilizes abrasive blasting to create a frosty appearance. Abrasive blasting is pivotal in achieving specific surface finishes for various applications. In the finishing of additively manufactured stainless steel surgical instruments, abrasive blasting or centrifugal finishing alone may be insufficient (Soja et al., 2020). It also plays a role in finishing 3D printed parts, impacting mineralization in composites (Puerta et al., 2021). Moreover, abrasive blasting is utilized in wood surface finishing, leading to notable color changes and presenting itself as a potential new finishing technique (Fonte et al., 2022).

2.2.1(c) Surface hardening

The surface hardening effect of abrasive blasting is evident in various applications, including the activation of teeth of saw blades in cotton processing machines, leading to increased wear resistance and durability of the saws (Shin et al., 2021). Furthermore, abrasive blasting is used as a physical method to achieve clean and 3D-structured lithium metal electrodes, demonstrating its potential for surface hardening applications (Lorrmann et al., 2021). The process also leads to changes in surface area size and roughness parameters, contributing to the modification of surface morphology and hardness (Draganovská et al., 2016). In summary, abrasive blasting is a versatile process that plays a crucial role in surface preparation, finishing, and hardening across diverse industries. It is essential for achieving optimal adhesion, specific surface finishes, and enhanced surface hardness, making it a fundamental technique in material processing and surface treatment.

2.2.2 Common issue with blasting

The blasting industry is associated with various common issues that have implications for material properties, surface quality, and environmental impact. Understanding and addressing these issues are crucial for optimizing blasting processes and ensuring sustainable practices (Bula et al., 2020; Park and Withey, 2021; Salmeron et al., 2013; Alves et al., 2022; Basdeki and Apostolopoulos, 2022).

Bula et al. (2020) meticulously investigated the deformation mechanism in mechanically coupled polymer-metal hybrid joints, highlighting the importance of understanding the ultimate tensile strength and rivet properties in the context of mechanical coupling. This study sheds light on the potential issues related to joint integrity and mechanical performance in hybrid structures, emphasizing the need to address these issues for optimizing blasting processes.

Meanwhile, Park & Withey (2021) discussed the formation and prevention of surface defects on the aerofoil of as-cast nickel-based single-crystal turbine blades, emphasizing the persistent challenge of surface scale formation in industry. Despite advancements, surface scale remains a common problem, impacting the quality and performance of critical components, underscoring the necessity of addressing these issues for optimizing blasting processes.

Salmeron et al. (2013) shifted the focus to laser therapy as an effective method for implant surface decontamination, highlighting the challenges associated with biofilm removal and surface decontamination in dental implants. This study underscores the importance of addressing biofilm-related issues in implant surfaces, emphasizing the need to optimize blasting processes for effective surface decontamination.

Alves et al., (2022) explored the ductility in dental ceramics, shedding light on the challenges related to brittleness and ductility in ceramic materials. Understanding the mechanical properties of dental ceramics is crucial for addressing issues related to material integrity and performance, highlighting the need to optimize blasting processes for improved material properties.

Meanwhile, Basdeki & Apostolopoulos (2022) scrutinized the effect of shot blasting process on the mechanical properties and anti-corrosive behavior of steel reinforcement, emphasizing the critical issue of corrosion resistance in reinforced concrete structures. This study highlights the importance of addressing corrosion-related challenges in structural integrity, underscoring the need to optimize blasting processes for enhanced anti-corrosive behavior.

Addressing these issues is essential for optimizing blasting processes, ensuring material integrity, surface quality, and environmental impact mitigation across diverse industrial applications. The insights gained from diverse studies drive the industry towards more efficient and sustainable practices.

2.2.3 Potential materials in abrasive blasting industries

Abrasive blasting is a widely used process in various industries, including the blasting industry, where it is considered a potentially unsafe operation due to potential exposure to airborne crystalline silica (Zulkarnain et al., 2021). The process involves forcibly propelling abrasive material onto a surface under high pressure, resulting in surface smoothing, roughening, contaminant removal, or shaping (Czepułkowska-Pawlak et al., 2020).

Research has shown that the choice of abrasive material used in the process can significantly impact the surface characteristics and corrosion behavior of the treated material (Kim et al., 2021). For instance, it has been reported that the existence of an abrasive on a steel surface blasted by alumina grit decreased the initial corrosion rate compared to when steel grit was used, indicating that the type of abrasive material can chemically modify the metal surface (Kim et al., 2021). Additionally, abrasive blasting has been utilized in the medical and dental fields to increase the surface area of implants or dental restorations, highlighting its diverse applications (Czepułkowska et al., 2019).

Furthermore, the industry has been actively seeking to improve safety standards, as evidenced by the development of intelligent robotic co-workers for industrial abrasive blasting (Carmichael et al., 2019). The process has also found widespread use in the marine industry for cleaning purposes (Zakaria et al., 2019b). Moreover, the method of abrasive blasting has been shown to have an effect on the wetting of steel surfaces by liquid zinc, indicating its influence on surface properties (Cecotka et al., 2016). Therefore, the choice of abrasive material in abrasive blasting processes is crucial, as it not only affects the surface characteristics and adhesion levels but also plays a significant role in safety and environmental considerations.

The abrasive blasting industry relies on a variety of blast media, each with distinct functions and environmental impacts. When selecting blast media, several considerations come into play to ensure optimal performance and environmental responsibility. Key factors include whether the media is suitable for the intended application in terms of shape and size, its recyclability, and its environmental impact during storage, use, and disposal.

2.2.3(a) Diamond

Diamond (Figure 2.4), renowned for its extraordinary hardness and resilience, has emerged as a notable abrasive material in various blasting applications. Leveraging diamond as an abrasive material brings distinctive advantages, such as unparalleled precision, superior cutting capabilities, and prolonged tool life. Several references delve into the diverse applications and merits of diamond as an abrasive material across different domains.

Figure 2.4: Diamond (www.Korotech.Lt., n.d.).

Terranova (2022) underscores the bioactive and mechanical properties of diamond, showcasing its potential in surface hardening applications. Meanwhile, Ren et al. (2023) explored the utility of diamond in genome mining, revealing its versatility in uncovering ribosomal peptides. In a comparative analysis, Persson & Sonnhammer (2022) highlighted diamond's suitability for ortholog analysis, comparing it to InParanoid-blast. Fan et al. (2022) applied diamond to analyze the gill transcriptome of endangered European freshwater mussels, illustrating its efficacy in biological research.

These references not only shed light on diamond's applications in functional annotation, metagenomics, and transcriptome analysis but also demonstrate its effectiveness in large-scale analyses. Studies by Gomes-dos-Santos et al. (2022) and Nelson et al. (2021) highlight diamond's efficacy in functional annotation and comprehensive analyses. Preprints by Vlasova et al. (2021) emphasize the speed and sensitivity of diamond, positioning it as a superior alternative to blast for orthology analysis and sequence annotation.

2.2.3(b) Garnet

Garnet (Figure 2.5) has emerged as a promising material in abrasive blasting industries due to its influence on surface characteristics and its potential for sustainable applications. Research has shown that abrasive blasting of structural steel results in significant retention of garnet abrasive residues, indicating its effectiveness as an abrasive material Poon et al. (2018). Additionally, garnet has been utilized as a waste material in construction applications, demonstrating its potential for sustainable use in various industries (Muttashar et al., 2018a). Furthermore, the embodiment of garnet abrasive particles on machining surfaces has been observed, highlighting its suitability for abrasive water jet machining and its impact on surface properties (Palaniyappan et al., 2022).

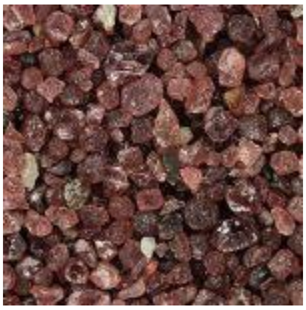

Figure 2.5: Garnet (Blaster, 2022).

The use of garnet as a blasting abrasive medium has been associated with low dustiness, low wear, and high hardness, contributing to its favorable machinability properties (Kulisz et al., 2020). Moreover, garnet of specific sizes has been employed as an abrasive blasting medium, further emphasizing its versatility in surface treatment processes (Shamsujjoha et al., 2015). The presence of significant amounts of abrasive residue embedded in garnet-blasted surfaces has been well-documented, underscoring its potential impact on surface properties (Poon et al., 2020).

Additionally, the valorization of spent garnets in cementitious materials and geopolymer concrete has been explored, indicating its potential for sustainable construction applications (Baera et al., 2022; Muttashar et al., 2018b; Muttashar et al., 2017). Furthermore, the use of waste garnet abrasive powders in various formulations has been reported, highlighting its potential for resource efficiency and waste reduction (Poggetto et al., 2022).

The high specific gravity and hardness of almandine garnet have positioned it as a principal abrasive for industrial uses, further emphasizing its suitability for abrasive applications (Oh et al., 2019). However, it is important to consider the potential environmental concerns associated with garnet as a waste spin-off of surface treatment operations, highlighting the need for sustainable management practices (Muttashar et al., 2018a; 2018b). Therefore, the diverse applications of garnet in abrasive blasting industries, construction, and machining underscore its potential as a versatile and sustainable abrasive material.

2.2.3(c) Jadecut

Jadecut (Figure 2.6), a potential material in abrasive blasting industries, has garnered attention due to its ability to influence surface topography and corrosion behavior. Research has shown that the careful selection of abrasive agents and blasting parameters can result in well-controlled surface properties (Lorrmann et al., 2021). Furthermore, the residue from blasting with alumina has been found to suppress corrosion, thereby improving adhesion and corrosion resistance of the treated surface (Kim et al., 2021).

Figure 2.6: Jadecut (HaiZhou, n.d.).

Additionally, the choice of abrasive material has been demonstrated to chemically modify metal surfaces, impacting the initial corrosion rate and the success of coating processes (Pratikno et al., 2021). Moreover, the influence of abrasive blasting on wetting properties and the lowest wettability provided by specific abrasive agents has been documented, indicating its impact on surface characteristics (Fonte et al., 2022). Furthermore, the sustainability-based characteristics of abrasives have been highlighted, emphasizing the importance of environmentally friendly abrasive materials in the blasting industry (Zulkarnain et al., 2021). It is crucial to note that the abrasive blasting industry has been actively seeking to improve safety standards, as evidenced by the development of intelligent robotic co-workers for industrial abrasive blasting (Carmichael et al., 2019).

In addition, the industry has been exploring sustainable cleaning technologies to minimize negative environmental impacts and ensure the safety of employees and equipment (Jassim & Khalaf, 2020). However, it is important to consider potential hazards associated with abrasive blasting, such as exposure to hazardous compositions like silica dioxide, which can jeopardize the corrosion protection offered by subsequent coating applications (Zakaria et al., 2019b). Therefore, the choice of abrasive material in abrasive blasting processes is crucial, as it not only affects surface characteristics and adhesion levels but also plays a significant role in safety and environmental considerations.

2.2.3(d) Ceramic

Ceramic (Figure 2.7) has garnered attention as a potential material in abrasive blasting industries due to its diverse applications and influence on surface properties. In the field of dentistry, ceramic materials are subjected to abrasive blasting to ensure adequate conditions on the metal surface for subsequent ceramic application, highlighting the role of ceramic in dental prosthetic procedures Czepułkowska et al. (2019). Moreover, the quality of joints between ceramic and metal components is influenced by the parameters of silicon carbide (SiC) abrasive blasting, emphasizing the importance of suitable abrasive materials for achieving optimal bonding in dental applications (Wołowiec-Korecka et al., 2022).

Figure 2.7: Ceramic (Ceramic Blasting Beads (sz): Versatile Applications Across Industries, n.d.).

Additionally, ceramics are known for their challenging machinability, posing a significant challenge for the industry (Pawar et al., 2015). The influence of abrasive blasting treatment on the wettability of ceramic surfaces has been studied, demonstrating the potential impact of abrasive processes on surface characteristics (Czepułkowska-Pawlak et al., 2021). Furthermore, the quality of ceramic-metal bonds is affected by the parameters of abrasive blasting, highlighting the importance of suitable abrasive materials for achieving strong and durable bonds (Maruo et al., 2016).

The use of ceramic waste powder in alternative cements showcases the potential for sustainable applications of ceramic materials in construction and composite materials (Shagñay et al., 2020). The diverse applications and properties of ceramic materials position them as promising materials in abrasive blasting industries, with the potential to influence surface properties, environmental sustainability, and various industrial processes.

2.2.3(e) Glass

Glass has emerged as a potential material in abrasive blasting industries due to its unique properties and diverse applications. Glass has been widely used in various fields, such as optoelectronics, biomedicine, and construction, owing to its excellent mechanical properties and versatility (Ali et al., 2017). Figure 2.8 shows glass beads as potential abrasive media.

Figure 2.8: Glass bead (Blaster, 2022).