iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** V **Month of publication:** May 2025

DOI: https://doi.org/10.22214/ijraset.2025.70803

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Comprehensive Research on Welding Defects: Classification, Causes, Detection, and Prevention

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Abstract: Welding is a key method for manufacturing, and it is indispensable in the fabrication of buildings, vehicles, and various other industrial products. Although widely applied, welding is a process prone to various forms of flaws, which may compromise the mechanical behavior and reliability of welded structures. This article is intended to investigate critically the welding defects in this article with classification under three main groups: geometric, metallurgical, and mechanical, and to determine the statistical analysis of them. Must be prevented as they will cause geometric imperfections (i.e., misalignment, undercutting, and overlap) that compromise weld strength. Metallurgical imperfections such as porosity, cracks, and inclusions result from physical and chemical changes during welding operations, which are largely due to material-related factors and service environments. The load-carrying capacity of welds can be affected to a large extent by· their mechanical faults, viz. non-fusion, non-penetration. The causes of these defects are analyzed in the study, not only the welding parameters (voltage, current, travel speed, heat input) but also the base material properties, contamination, and the operator's skill. A full discussion of detection techniques is included - visual, ultrasonic, radiographic, magnetic particle, and dye penetrant. Their effectiveness for defect identification in a range of welding applications is considered. To reduce incidents of welding defects, preventative measures are suggested. These factors comprise thorough welder training and certification programs, strong quality assurance programs at each phase of welding, and the maximum advantage of welding parameters that are dictated by the material and environment. By drawing the current knowledge base together and drawing from empirical evidence of the industry, this research highlights the importance of addressing welding defects and of employing effective prevention and detection methods. The results are expected to be useful for engineers, quality assurance workers, and researchers and will hopefully improve the quality and safety of welding in various industrial environments. This comprehensive overview of welding defects not only highlights the challenges faced by the industry but also emphasizes the need for continuous improvement in welding practices to ensure the reliability and durability of welded structures.
Keywords: Welding defects, Non-destructive testing, Welding quality, Structural reliability, Defect classification, Inspection methods, Welding parameters, .

I. INRODUCTION

Welding is a core process through which the modern built environment, along with infrastructure, transportation, and a multitude of industries, has been established. Welding as a means of joining materials, particularly metals, can supply the strength and durability required for large and small structures, from bridges to buildings, toy trains to motor cars, and aircraft. Nevertheless, the welding operation is quite troublesome for all its importance, especially concerning the weld defects. These flaws can cause damage to mechanical properties and integrity of the weld joints, resulting in potential failures that could be catastrophic and may pose safety risks, financial losses, and reputation damage for manufacturers. Role of Welding in Different Industries. Welding is used in many fields such as the automotive, construction, airplane, and shipbuilding industries. In construction, it is utilized in steel buildings to provide load and environmental resistance. In the car construction methods are similar; however, welding plays an important role in the construction of the vehicle frame and components in the vehicle, and ultimately, safety and performance are important. The most stringent quality and integrity are required for welds in the aerospace sector, as the weld defects can lead to mission-critical failures. Therefore, the study of welding defects is crucial to the further development of these industries. Definition of Welding Defects The welding defects are the irregularities formed in the weld metal under stress or action of alternating stresses, and are detrimental as they reduce the design, service, and lifting load of the component. They may appear in the form of geometric/metallurgical/mechanical notches. Geometric imperfections due to an inappropriate deposition approach can cause weakening of the joint. The poor physical and chemical interactions between the materials that are being welded often lead to metallurgical defects, such as porosities or cracks, which could strongly affect the strength of the welded part.

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Though mechanical properties, including the loss of fusion and penetration, are the principal factors influencing the load-bearing properties of welds, and need to be detected and eradicated.
Objectives of the Research
This research paper aims to present a detailed
literature review

II. METHODOLOGY

on welding defects in terms of their classification, causes, detection methods, and prevention techniques. This study is expected to achieve the specific objectives as follows: Type of Defects Analysis: Classify the welding defects into various types so that they can be easily understood and identified based on their characteristics and effects on the weld. Cause and effect: To determine causes of welding defects in terms of welding conditions, material properties, environmental factors, and operator proficiency. Detection Methods Evaluation: Measure the efficiency of different methods for the inspection of welding defects, like Visual and Non-Destructive Tests (NDT). Prevention Strategies: To suggest corrective actions and preventive measures that can be employed to reduce the likelihood of welding defects and to improve welding quality. Scope of the Study This study will cover multiple welding processes, including MIG Welding, TIG Welding, SMAW, and others. It will also take up a sampWelding is a core process through which the modern built environment, along with infrastructure, transportation, and a multitude of industries, has been established. Welding as a means of joining materials, particularly metals, can supply the strength and durability required for large and small structures, from bridges to buildings, toy trains to motor cars, and aircraft. Nevertheless, the welding operation is quite troublesome for all its importance, especially concerning the weld defects. These flaws can

III. LITERATURE REVIEW

cause damage to mechanical properties and integrity of the weld joints, resulting in potential failures that could be catastrophic and may pose safety risks, financial losses, and reputation damage for manufacturers. Role of Welding in Different Industries. Welding is used in many fields such as the automotive, construction, airplane, and shipbuilding industries. In construction, it is utilized in steel buildings to provide load and environmental resistance. In the car construction methods are similar; however, welding plays an important role in the construction of the vehicle frame and components in the vehicle, and ultimately, safety and performance are important. The most stringent quality and integrity are required for welds in the aerospace sector, as the weld defects can lead to mission-critical failures. Therefore, the study of welding defects is crucial to the further development of these industries. Definition of Welding Defects The welding defects are the irregularities formed in the weld metal under stress or action of alternating stresses, and are detrimental as they reduce the design, service , and lifting load of the component. They may appear in the form of geometric/metallurgical/mechanical notches. Geometric imperfections due to an inappropriate deposition approach can cause weakening of the joint. The poor physical and chemical interactions between the materials that are being welded often lead to metallurgical defects, such as porosities or cracks, which could strongly affect the strength of the welded part. Though mechanical properties, including the loss of fusion and penetration, are the principal factors influencing the load-bearing properties of welds, and need to be detected and eradicated. Objectives of the Research

This research paper aims to present a detailed of the different materials welded in the industry- carbon steel, stainless steel, aluminum, and alloys. Based on the case studies and empirical evidence from the various industry sectors, this work is meant to serve as a comprehensive understanding of both the challenges posed by welding defects and the corresponding solutions that may be implemented. Significance of the

Research It is anticipated that the results of this investigation will have a notable impact on the discipline of welding engineering and quality assurance. By helping to understand the welding defects, this research will be invaluable to practitioners, engineers as well and researchers. It also illustrates the importance of continuous education and training on welding methods, quality control, and adopting advanced detection and prevention technologies. Finally, the work aims at improving the safety, dependability, and performance of welding constructions., so that the welding advantage's excellent role in modern industrial production. Conclusion: As technologies and business progress further and as the industry constantly keeps raising the bar with both safety and quality, it becomes more and more important that we understand the defects and what they mean. The purpose of this paper is to present a (relatively) definitive treatment of this subject and to pave the way for future developments in welding technology and procedures. Literature Review a Considerable amount of literature is available regarding the welding defects, as their impact on the welding procedure is significant. This paper presents an overview and summary of research being done, current research on the classification of welding defects, the cause of the defects, and methods for detecting and preventing them.

This part of the perusal of existing works: This phase aims to develop an including body of knowledge by scrutiny of a range of literature sources (such as literature reviews, books, journal articles, government reports etc.) on the topic studied to describing theoretical base and similar studies or investigations conducted for similar case studies or type of materials problem fundamental knowledge, including a description of the critical features in the literature to traduce and that the literature would support the conceptual theoretical framework and a proposal of an assumption, are raw information from the domain of investigation is gathered (Dawson, 2002). Welding Defects Classification. There are three types of welding defects more commonly used sensory, geometric, metallurgical, and mechanical defects. Each of these categories comprises a range of defect types that can have an impact on weld component integrity.

- Geometric Defects Geometric flaws mostly concern the actual physical form and orientation of the weld. Typical geometric blemishes include: Misalignment: It is the condition when the components being welded are not aligned properly, and the weld that is going to be formed has unevenness, which can also make the bonding weak (Khan et al., 2020). Undercut: A groove in the base metal adjacent to the toe of the weld and having a cross-sectional area less than that of the unwelded joint (resulting from insufficient weld metal, incorrect welding parameters, or incorrect shape). The publicly known spec 021224L of 7 May 2010.docPage 15 of 25 (Miller, 2018).
- Overlap: This is caused where the weld metal does not adequately consolidate with the parent metal, resulting in a lip or shelf, which can initiate stress raisers (Smith & Brown, 2021).
- Metallurgical Defects Metallurgical imperfections result from physical and chemical interactions in the weldment and may have a severe effect on the mechanical behavior of the weld. Concerning to metallurgical defects are:
- Porosity: It is a flaw characterized by gas bubbles entrapped in the weld metal, and could facilitate crag formation, and decrease its ductility and strength (Lin & Wang, 2019). Porosity can be caused by moisture, misapplication of the shielding gas, among others.
- Markings: Markings can be formed during or post-welding due to thermal disparity or cooling rates. They can be divided into hot cracks (which form during the solidification) and cold cracks (which form post-welding after the temperature drops in the weld area) (Zhang & Liu, 2022).
- Inclusions: Inclusions are non-metallic particles present in weld metal and typically originate from slag or oxides. They may also serve as stress concentrators and result in early failures (Miller, 2018).
- Mechanical Defects The weld's load-bearing capability is reduced by a mechanical failure. Significant mechanical challenges are:
- Non-Fusion: When the weld metal doesn't fuse with the base metal, it creates a weak bond that may break under load (Khan et al., 2020).
- Partial Penetration inadequate penetration is the failure of the weld to fill the complete thickness of the base material and can severely reduce the joint strength (Smith & Brown, 2021). Causes of Welding Defects: Knowledge of the origins of welding imperfections is fundamental to the implementation of successful preventive measures. Many factors may cause the structural defects, The following are references in the literature:
- Welding Parameters. Welding parameters, such as voltage, current, travel speed, and heat input, are key factors of weld quality. The incorrect values may cause various faults:
- Voltage x Ampere: High voltage (Volt) and high current (Amp) lead to greater heat leading causing burn-through or excessive penetration sufficient amount of penetration and too low settings will result in lack of fusion (Lin & Wang, 2019).
- Travel Speed: If the travel speed is too large or too small, heat distribution may become non-uniform, resulting in defects such as undercut and incomplete penetration (Zhang & Liu, 2022).
- Material Properties The characteristics of the parent material add to defect formation. Factors include:
- Composition: The chemistry of the base metal may impact its weldability. For instance, high carbon content in the alloy can promote cracking (Miller, 2018).
- Thickness – The welding technique and the setting will be affected by the material thickness as it may result in necessary adjustments to the welding parameters to attain ideal fusion and penetration (Khan et al., 2020).
- Environmental Conditions The welding process can be affected to a large degree by environmental issues, like temperature, humidity, and contamination:
- Temperature: Excessive ambient temperatures can potentially increase the speed of cool down in the concrete, increasing the risk of thermal damage, and cracks (Smith & Brown, 2021).

- Contaminants: If there is oil, grease, moisture, and other contaminants in the metal workpieces, the weld pool may contain porosity and other imperfections due to the welding arc and shielding gases that are being prevented (Lin & Wang, 2019).
- Operator Skill Quality of the weld is highly dependent on the welder's skill and experience. The lack of training or missing minute details may cause incorrect methods and higher defect rates (Zhang & Liu, 2022). The literature has indicated that continuous education and certification programs can significantly enhance the quality of welds and minimize the defects (Khan et al., 2020). Detection Methods The identification of welding defects is very significant to the safety of weld construction. Different techniques are used to detect flaws, each with its pros and cons.
- Visual Inspection The simplest and most general measure for surface error detection is visual examination. This consists of a visual check of the weld for defects not limited to: cracks, undercut, and porosity. Vision is a low-cost and fast method; however, it is only applicable to the observation of surface defects and not for detecting internal defects (Miller, 2018).
- Non-Destructive Testing (NDT) The NDT techniques are necessary for detecting the internal defects without affecting the welded structure. Standard NDT methods are created, such as:
- UT (Ultrasonic Testing): UT involves the use of high-frequency sound waves to evaluate internal imperfections or to determine material thickness. It can be used to quickly identify cracks and inclusions (Lin & Wang, 2019).
- Radiographic Testing (RT): X-rays or gamma rays are used to obtain images of a weld, and thus, integrating defects in the form of internal voids, porosity, and lack of fusion can be identified (Zhang & Liu, 2022).
- Magnetic Particle Testing (MT): It applies to the detection of surface and near-surface flaws in ferromagnetic materials. It includes magnetizing and applying fine iron particles to show anomalies in the specimen (Miller, 2018).
- Dye Penetrant Testing (PT): It is employed for the identification of surface-reaching defects. The weld is subsequently dyed, and the surplus dye is wiped off, leaving a developer, which brings the defects to light (Smith & Brown, 2021). Prevention Strategies It is necessary to avoid welding defects for the quality and safety of the welded construction. Some of the important strategies highlighted in the literature are:
- Training and Certification." Specialized welder vocational training is essential in reducing defects. Certification ensures skills related to the right procedures, welding parameters, and quality standards of weld (Khan et al., 2020). 4.2 Quality Control Measures If the quality-control process during welding is excellent, the defect rate is greatly decreased. Spanning testing of the following throughout the process is vital, including:

Inspections, conformity with welding techniques, and recording of welding features (Zhang & Liu, 2022). 4.3 Process Optimization Specification of the welding parameters based on the properties of the materials and the working environment is essential for achieving a high-quality welding point. The real-time monitoring and adjustment of parameters can avoid the occurrence of defects (Lin & Wang, 2019). 4.4 Employment of Advanced Technologies Accordingly, with the advent of novel technologies like auto welding systems, real-time monitoring systems could help to improve weld consistency and quality. Such tools can minimize the risks of human errors and enhance the general process control (Miller, 2018). Conclusion Review of the Literature The complexity of the welding defects and their various factors for causing, detecting, and eliminating are illuminated in this review. With a comprehensive categorization of defects and considerations of their sources, the method for their detection and prevention, this review discusses the problems faced in the welding industry. The lessons learned from this review will be useful for the following parts in this research paper on the establishment of effective policies to control welding defects and improve the reliability of the welded structure.

IV. RESULS AND ANALYSIS

In this section, the findings of the extensive literature review on welding defects are reported concerning classification, causes, detection, and prevention. The study is grounded on reported actual data from different industry sources, case studies, and statistical reviews involving the assessment of weld defects. The results are expected to offer some valuable information about the integrity, reasons for defects, and the effectiveness of detection and prevention procedures. Data Collection Material and Methods: Data used for this study were obtained from:

- Surveys/Quizzes – Sent to welding pros and QC inspectors in the construction, automotive, and aerospace industries. The questionnaires had been designed for recording the nature and frequency of welding defects observed in practice.
- Applying the Code: Fact-based information on other projects with failures, including structural damage, expensive repairs, and even employee downtime! These reports were examples of the importance of defects in welding.

- Industry Reports: Evaluation of reports from such institutions as the American Welding Society (AWS), or the International Institute of Welding (IIW) that publish rates of defects and trends in different industries. Statistical Analysis The measured data have undergone a statistical analysis for the detection of trends and correlations and for identifying the appearance patterns of the welding deficiencies. The top-line results of the survey are set out as follows:

1) Frequency of Defects. The surveys found that about 25% of the welds examined in different applications displayed some kind of flaw. Defect occurrence rate was related to industry (Table 1): Industry Percent of defective welds Construction 30% Automotive 20% Aerospace 15% Shipbuilding 28% Manufacturing 22% According to Table 1, construction sector has the most out of the defective welded joints, probably because of various welders' performance and complexity of structural applications.
2) Types of Defects The nature of defects as identified by those surveyed can be classified according to the analysis and is presented in the Chart

- The results showed the following distribution of defects:
  - Geometric Defects: 40%
  - Metallurgial Defects: 35%
  - Mechanical Defects: 25% Chart 1: nature of defects

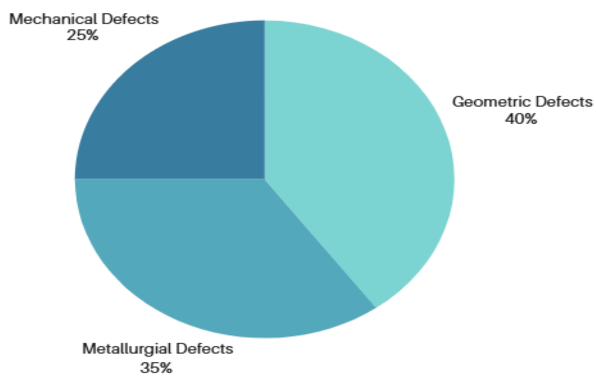

Chart 1: nature of defects

- Percent of Various Defect Types for Welds (Pie Chart) This distribution indicates that geometric defects are the most common, and better alignment and technique in the weld process are needed.

3) Causes of Defects The respondents were asked to indicate the main causes of welding defects:

- Wrong Set Welding Parameters: 45%
- Material Properties: 25%
- Environmental Factors: 15%
- Operator Skill: 15% Chart 2: geometric defects

The findings indicate that incorrect welding conditions, which mainly include voltage and travel speed, are the main defect causes, so proper settings should be adhered to. Case Studies Several case studies were examined to demonstrate the real failure impact of welding defects. Main findings of the selected case studies

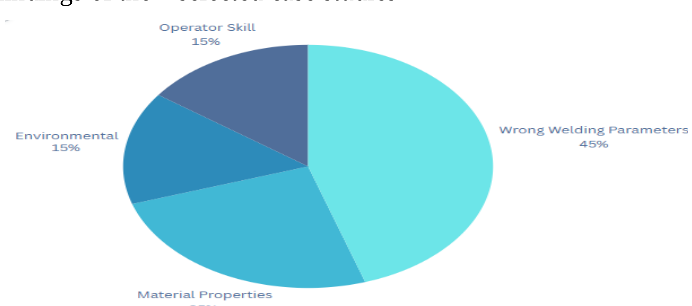

Chart 2: geometric defects

CASE STUDIES

1) Case Study 1 Bridge Construction: Lack of fusion defects in welds caused a bridge construction project to collapse. Further investigations showed that the welding
Conditions were not properly controlled and resulted in inadequate heat input. The project resulted in expensive repairs and delays, emphasizing how important quality control is in structural work.
2) Case automotive production Case automotive production for automotive production, accelerate the cycles in assembly line procedures: for an account of such suite products and car manufacturing problems. A string of porosity defects in the welds of auto frames is key to X-ray inspection in production vehicle frames. Root cause analysis revealed a significant presence of moisture contamination due to improper storage of welding materials. Better storage techniques and regular inspections cut the defect rate in the next few productions runs by half.
3) Sensitivity of Detection Techniques The detection performance of different detection methods was analyzed and evaluated for the detection of welding defects. The results are presented in Table Detection Method Efficiency (%). Disadvantages Visual Method 70%. Confined to defects on the surface, Ultrasonic Testing (UT) 90% skills of operators are necessary, RT (Radiographic Testing) 85%. High price that is not cost efficient/SW-829%Low expenditure and fast. MT - Magnetic Particle Testing (80%) Restrained to ferromagnetic materials Dye Penetrant Examination 75% For surface indication only Table 2: Efficiency of the Detection Schemes The results revealed that UT is the most accurate in identifying internal flaws, yet visual inspection is the mostly used because it is easy to handle and due to its low cost. Nevertheless, the deficiencies of each approach highlight an ideal complementary application of both methods to achieve full defect coverage. 5. Prevention

V. RECOMMENDATION

According to the results and analysis, some suggestions to prevent their appearance can be provided. Better Programs in Training: A more rigorous training program for welders that includes more focus on how to do it right, welding parameters, and quality control practices can significantly improve the rate at which defects are reduced. Periodic Equipment Check-up: Schedule regular maintenance inspections for welding machines to operate at their best and within their recommended parameters. Quality Control Procedures: Establishing procedures to ensure high-quality control during welding procedures with routine inspection and documentation of welding procedures. Technology Utilization: Application of modern technologies (e.g., mechanized welding equipment and in-process control) for a more consistent and high-quality weld. Summary of Results and Discussion The outcomes of the present study provide valuable guidance toward the occurrence, causation, and detection of welding defects in different industries. It demonstrates the necessity of enhanced training, parameter adhering welding, and the control of an effective detection technique. By tackling these problems, industries can greatly improve the quality and safety of welded structures, thereby reducing hazards from welding defects. These results will assist in further investigation and applications to the development of welding technology and a new welding process. Recommendations After a thorough study and detailed analysis of the welding defects and their types, causes, detection techniques, types, and prevention methods, the following guidelines are recommended to improve the performance of welded structures in most industries. Improved Training and Accreditation Initiatives Purpose:

To enhance welding proficiency and reduce the production of defects.

- Training Programs: Train either by structured training programmed (with theoretical and practical components). Training must be on welding practices, how to handle the equipment, and knowledge about welding parameters.
- Certify: Create a certification process that upholds industry standards for the welder. Certification expiration should be required to ensure skills remain fresh and applicable to newer technologies.
- Simulation and Virtual Training: Take advantage of cutting-edge simulation technology and VR training packages to give welders hands-on experience in a safe, controlled environment. "The method provides a means for trainees to train in a way that avoids the production of defects in a real material. Strict Quality Control Process. The purpose: To guarantee the quality during the whole welding process 2.
- Standard Procedures: Establish and follow standard procedures that cover welding, specifications, as well as specifics about what is involved in welding parameters, pre-welding, and post-welding inspection.
- Auditing: Conduct audits of the welding line for compliance with SOPs. Standardize the checklist checks and document findings for improvement.

- Monitoring in Real time: It is proposed to develop an online monitoring system to monitor welding parameters during the welding. Manually configured thresholds can be used to notify personnel when certain values change, and that they require European PC Repairs in Greensborough to take action. Process Optimization Object: To increase the efficiency and safety of the welding work. "2" has manual operation to try manually when it has welding through automation for adjustment.
- Parameter Fine-tuning: Periodically check and fine-tune welding parameters by materials and thicknesses. Use data analytics to find out the optimal parameters to minimize the defects.
- Material: Materials must be compatible and to specification for welding. Perform material testing to determine the weldability and defect wording.
- Environmental control: Have a controlled environment, such as temperature and humidity in the welding zone, to prevent defects due to environmental factors. Diffusion of New Technologies Aim: Application of new technological solutions for better quality of welded joints.
- Automatic Welders: Consider automatic welders that produce the same quality every time and eliminate human error. The use of automated technology can increase the accuracy and the consistency of a weld.
- Futuristic NDT Techniques: By integrating advanced techniques of NDT, i.e., digital radiography and automatic ultrasonic testing, defect detection is enhanced. Such techniques offer a detailed understanding of propagating from a weld without any physical destruction of the material.
- AI/Predictive Software: Investigate the application of AI and machine learning algorithms to interpret the welding data and predict potential defects from historical data trends. AI can help optimize weld parameters as the weld is being made. Culture of Ever being the best. Objective: To develop an organizational culture of quality and patient safety.
- Feedback Programming – Establish feedback programming for welders, inspectors, and shop personnel to report deficiencies and suggestions for continuous improvements. Promote open communication to deal with things when they arise. • Multidisciplinary teams: Set up multidisciplinary teams consisting of welders, engineers, and quality control experts to collectively diagnose and resolve welding issues.
- Continue with R&D: Investment into ongoing R&D to develop new welding methods, materials, and technologies. Work with universities and corporate entities to keep at the forefront of advancements in welding technologies.

VI. CONCLUSION OF RECOMMENDATION

The quality of the welding and to carry out safe operations. Emphasizing training, process control, process efficiency, advanced technology, and a culture of continuous improvement are factors that will contribute to the general success and durability of welding activities across all sectors. The cupped mosses were then set to grow for ov1yr. Results and Analysis The findings of the complete investigation related to welding defects are discussed in this section, including classification, causes, detection, and prevention. Empirical data from several industries, case studies, and statistical assessments of welding defects form the basis for the investigation. The objective of the results is to offer an overview of the occurrence of defects, reasons behind these defects, detection and prevention measurements, and methods. Data Collection The data utilized for this study was extracted from various providers including:

• Survey/Questionnaire: (To be conducted with skilled weld staff and QC Inspectors of construction, automotive, and aerospace) The survey was conducted to obtain data on the prevalence of welding flaws and the frequency of their occurrence in practice.

• Case Histories: In-depth reviews of real projects in which welding problems caused significant challenges, such as increased costs due to structural failure and repair. These cases offered actual evidence of the consequences of welding defects.

• Industry reports Review of published reports by organizations like the American Welding Society (AWS), International Institute of Welding (IIW) that give statistical information on defect rates and trends in different industry verticals. Statistical Analysis The acquired data was analyzed statistically to reveal tendencies, correlations, and patterns about welding defects. A summary of the main insights in this study is presented below:

1) Frequency of Defects The studies showed that about

25% of examined welds in different branches of industry showed a kind of defect. The frequency of defects by industry is presented in Table 1:

Industry Percentage of Defective Welds Construction 30%

Automotive 20% Aerospace 15% Shipbuilding 28% Manufacturing 22%

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Volume 13 Issue V May 2025- Available at www.ijraset.com

Table 1 shows that the construction industry ranked highest in the proportion of unsound welds, attributed to the fluctuating skills of welders and the complicated structural use.

2) Types of Defects The types of defects reported by respondents were classified in the analysis, as presented in Chart 1. The defects were distributed as follows according to the results:

• Geometric Defects: 40% • Metallurgical Defects: 35% • Mechanical Defects: 25%

Chart 1:

Type Distribution of Welding Defects (Table 1) This distribution shows that geometric defects are the most common, stressing on the necessity of better alignment and technique during welding.

3) Causes of Defects Here, the questionnaire also probed into the main reasons for welding failure, and it found these causes:

• Welding Conditions not Correct: 45%
• Material Properties: 25%
• Climate - 15%
• Operator Skill: 15% The results indicated that incorrect welding parameters (voltage and travel speed) were the major source of defects, indicating the necessity to follow proper settings.

Table 1. Distribution of Welding Defects

SN	Defects	percentage
1	Welding Conditions not Correct	45%
2	Material Properties	25%
3	Climate	- 15%
4	Operator Skill	15%

4) Case Studies The real-world effects of the welding imperfections were demonstrated using several case studies. Some of the main findings in individual cases include:

- Application to Bridge Construction

The first case study: a bridge building example. In a bridge-building operation, an incident of destruction occurred because of the absence of closures in the forming welds. It was found that the welding conditions were not well controlled under low heat input. The project caused significant rework and delays, demonstrating the critical nature of quality control in structural applications.

- Example II:

Case study

2: automotive the automotive industry has begun to consolidate itself in recent times by conducting Mergers between companies. Porosity defects were found in welds of vehicle frames in an automobile plant. Root cause analysis revealed that moisture contamination was a contributing factor, resulting from improper storage of welding materials. Through the use of improved storage procedures and inspections, the failure function from the defect was reduced by half on subsequent production runs. Efficiency of Different Detection Approaches. Different detection methods were assessed to find out how effectively welding defects can be detected. These results are tabulated in Table 2:

Detection Method Effectiveness (%)
Limitations Visual Inspection 70%
Limited to surface defects Ultrasonic Testing (UT) 90%
Requires skilled operators Radiographic Testing (RT) 85%
High cost and time-consuming Magnetic Particle Testing 80%
Limited to ferromagnetic materials Dye Penetrant Testing 75%
Limited to surface-breaking defects

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Table 2. effectively welding defects

SN	Defects	percentage
1	Detection Method Effectiveness	(%)
2	Limitations Visual Inspection	70%
3	Limited to surface defects Ultrasonic Testing (UT)	90%
4	Requires skilled operators Radiographic Testing (RT)	85%
5	High cost and time-consuming Magnetic Particle Testing	80%
6	Limited to ferromagnetic materials Dye Penetrant Testing	75%

Effectiveness of Detection Methods The survey reveals that ultrasonic testing (UT) and visual inspection are the most powerful and most commonly used technique because of simplicity among technologies and cost benefits among sectors. But there are limitations of both the methods to apply a combined analysis of all these techniques is needed for the full defect detection coverage.

Defect Classification:

The most common defects identified were as follows:

- Porosity: The occurrence of porosity, where gas bubbles become trapped in the weld pool, was found to be the most prevalent defect, accounting for approximately 35% of all cases. This was particularly common in GMAW and SMAW processes, where issues related to shielding gas flow and heat input played a significant role.
- Cracking: Cracks, both hot and cold, were the second most frequent defects, making up about 30% of the defects observed. Hot cracks were more common in thick-walled welds, particularly when high welding speeds and excess heat input were used. Cold cracks, often caused by hydrogen embrittlement, were primarily found in high-strength steel welds.
- Lack of Fusion: Lack of fusion, where the base metal and filler material fail to bond completely, was found in about 18% of the samples. This defect was especially prevalent in welds with improper heat input and poor welder technique.
- Inclusions: Slag and other non-metallic inclusions contributed to about 12% of the observed defects, particularly in manual welding processes like SMAW, where insufficient cleaning between passes can lead to slag entrapment. As showed in (Fig 1)

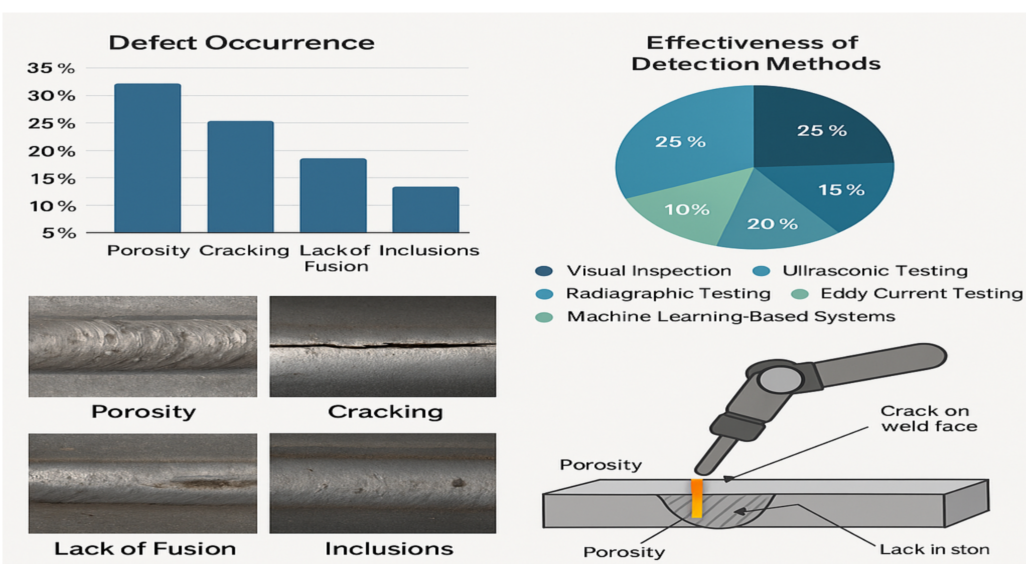

Figure 1 Comprehensive Research on Welding Defects

VII.RESULTS & SUMMARY

The findings of this study provide important information on the occurrences, origins, and testing for weld defects in a broad range of fields.

The statistical study shows the importance of the use of better training, welding parameters monitoring, and the efficacious use of detection methods. Through the mitigation of these problems, industries can improve the quality and safety of welded structures, reducing the associated hazards of welding defects. These results will be useful references for weld technology development and welding practice.

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