

weld fillet size calculation

weld fillet size calculation plays a critical role in ensuring the strength, durability, and safety of welded structures across various industries. Understanding how to accurately determine the appropriate fillet weld size is essential for fabricators, engineers, and inspectors to meet design requirements and comply with welding codes and standards. This process involves assessing factors such as load conditions, material thickness, joint configuration, and welding procedures. Proper weld fillet size calculation helps prevent structural failures, optimize material usage, and reduce costs associated with over or under welding. This article provides a comprehensive overview of the principles, methods, and best practices for weld fillet size calculation, along with important considerations for quality control and inspection. The following sections will cover fundamental concepts, calculation techniques, applicable standards, and practical examples to enhance understanding and application in real-world scenarios.

- Understanding Weld Fillets and Their Importance
- Fundamentals of Weld Fillet Size Calculation
- Standards and Codes Governing Fillet Weld Sizes
- Methods for Calculating Fillet Weld Size
- Factors Affecting Fillet Weld Size Determination
- Inspection and Verification of Fillet Weld Sizes

Understanding Weld Fillets and Their Importance

Weld fillets are triangular cross-sectional welds used to join two surfaces at approximately right angles. They are among the most common types of welds used in structural and mechanical applications due to their simplicity and effectiveness. The size of a fillet weld directly influences the joint's strength and fatigue resistance. An adequately sized fillet weld ensures proper load transfer between the joined members, preventing failures such as cracking, distortion, or separation under stress.

Fillet welds are typically characterized by their leg length, throat thickness, and weld length. These dimensions are crucial for calculating the weld's effective area and, subsequently, its load-carrying capacity. Understanding these parameters is the foundation for accurate weld fillet size calculation.

Definition of Fillet Weld Size

The fillet weld size is commonly defined by the leg length, which is the distance from the root of the weld to the toe along the adjoining pieces. This measurement is essential for determining the weld's throat thickness, which represents the shortest distance from the root to the hypotenuse of the triangular weld cross-section. The throat thickness is a critical factor because it defines the effective weld area that resists applied stresses.

Applications of Fillet Welds

Fillet welds are extensively used in various applications such as:

- Structural steel fabrication
- Shipbuilding and marine structures
- Automotive and heavy machinery manufacturing
- Pipeline and pressure vessel construction
- General fabrication and repair work

Fundamentals of Weld Fillet Size Calculation

The process of weld fillet size calculation involves determining the appropriate weld leg length and throat size to safely carry the applied loads. It requires an understanding of the types of stresses the weld will experience, including tensile, compressive, shear, and bending forces. The calculation aims to ensure that the weld area has sufficient strength to withstand these forces without failure.

Basic Geometric Relationships

For a fillet weld with equal legs, the effective throat thickness (t) can be calculated using the formula:

$$t = \text{leg length} \times 0.707$$

This relationship is derived from the geometry of a right-angled triangle, where the throat is the perpendicular distance from the root to the hypotenuse. Accurate measurement of leg length is essential for precise weld size calculation and ensuring the weld meets design specifications.

Load Considerations

Weld fillet size must be calculated based on the anticipated loads, including static and dynamic forces. Key load factors include:

- Shear stress: The primary stress in fillet welds, especially in lap joints and T-joints
- Tensile and compressive stresses: Occur depending on load direction and joint configuration
- Bending moments: Affect the weld size in joints subjected to bending forces

Understanding these forces helps in selecting an appropriate weld size and ensuring safety margins are maintained.

Standards and Codes Governing Fillet Weld Sizes

Various national and international standards provide guidelines and requirements for weld fillet size calculation, ensuring consistency, safety, and quality in welded structures. Compliance with these standards is mandatory for many industries and projects.

American Welding Society (AWS) Standards

The AWS D1.1 Structural Welding Code is one of the most widely referenced standards for fillet weld sizing in structural steel applications. It specifies minimum weld sizes, allowable stresses, and inspection criteria to ensure weld integrity and performance.

American Society of Mechanical Engineers (ASME) Codes

The ASME Boiler and Pressure Vessel Code (BPVC) provides detailed instructions for fillet weld sizing in pressure vessels and piping systems. It emphasizes weld strength, quality control, and inspection to prevent leaks and failures under high pressure and temperature conditions.

Other Relevant Standards

Additional standards that influence weld fillet size calculation include:

- ISO 5817 – Weld quality levels for steel, nickel, titanium, and their

alloys

- EN ISO 9692 – Welding and allied processes joint preparation
- API 650 – Welded tanks for oil storage

Methods for Calculating Fillet Weld Size

Several methods exist for calculating the appropriate weld fillet size, ranging from simple geometric approaches to more advanced engineering analyses. The selection depends on the complexity of the joint and loading conditions.

Empirical Formulas

Empirical formulas based on industry standards and experimental data provide quick and reliable means to estimate fillet weld sizes. For example, the minimum fillet weld size may be determined based on the thickness of the thinner member as prescribed by AWS D1.1:

Minimum leg size = 1/16" to 1/4" depending on base metal thickness

These formulas simplify decision-making in routine welding tasks.

Stress-Based Calculation

This method involves calculating the required weld area by dividing the applied load by the allowable weld stress. The leg length is then derived from the throat thickness and weld length. The process includes:

1. Determining the applied load on the weld
2. Selecting the allowable shear or tensile stress for the weld material
3. Calculating the necessary throat area to resist the load
4. Deriving the fillet weld leg length using geometric relationships

Finite Element Analysis (FEA)

For complex joints and critical applications, FEA software can simulate stress distribution and deformation in welds. This advanced method allows precise optimization of fillet weld size to balance strength and material use efficiently.

Factors Affecting Fillet Weld Size Determination

Several factors influence the calculation and selection of the proper fillet weld size. These must be carefully considered to ensure weld performance and compliance with design requirements.

Material Properties

The mechanical properties of the base metals and filler materials, such as yield strength, tensile strength, and ductility, directly impact the allowable stresses for weld sizing. Different materials require adjustments in weld size to accommodate their specific characteristics.

Joint Configuration and Position

The type of joint—whether T-joint, lap joint, or corner joint—influences the direction and magnitude of stresses on the weld, affecting size requirements. Additionally, welding position (flat, horizontal, vertical, or overhead) may affect weld quality and size selection due to accessibility and gravity effects.

Service Conditions

Environmental factors such as temperature, corrosion, cyclic loading, and fatigue must be accounted for in weld fillet size calculation. Structures subjected to harsh conditions often require larger or specially prepared welds to maintain integrity over time.

Welding Process and Technique

The choice of welding process (e.g., SMAW, GMAW, FCAW) and the welder's skill level can influence the achievable weld size and quality. Proper technique ensures the calculated weld size is effectively realized in the finished joint.

Inspection and Verification of Fillet Weld Sizes

After weld fillet size calculation and execution, inspection is vital to verify that the weld meets specified dimensions and quality standards. Accurate measurement and testing help detect deficiencies and prevent structural failures.

Visual Inspection

Visual inspection is the first step in checking fillet weld size. Inspectors measure leg lengths and look for defects such as undercut, porosity, and incomplete fusion. Tools like weld gauges facilitate quick and reliable size verification.

Non-Destructive Testing (NDT)

NDT techniques such as ultrasonic testing, radiography, and magnetic particle inspection assess internal weld quality without damaging the joint. These methods ensure the weld size corresponds to the required strength and that no hidden flaws compromise performance.

Documentation and Record Keeping

Maintaining detailed records of weld fillet size calculations, inspections, and test results is essential for quality assurance and regulatory compliance. Proper documentation supports traceability and facilitates future maintenance or audits.

Frequently Asked Questions

What is the formula for calculating weld fillet size?

The weld fillet size is typically determined by measuring the leg length of the triangular cross-section of the fillet weld. The size is the length of the legs, which are equal in a symmetrical fillet weld.

How do you determine the required fillet weld size for a given load?

The required fillet weld size can be calculated by analyzing the load and using welding codes or standards such as AWS D1.1, which provide formulas to relate the load to the effective throat thickness and leg size of the weld.

What is the effective throat in fillet weld size calculation?

The effective throat is the shortest distance from the root of the fillet weld to the face of the weld, representing the weld's actual load-carrying area. It is calculated as the leg size multiplied by $\sin 45^\circ$, approximately 0.707 times the leg size.

Why is fillet weld size important in structural design?

Fillet weld size is critical to ensure the welded joint has sufficient strength to carry the applied loads safely without failure, maintaining structural integrity and compliance with design codes.

How does the leg size relate to the throat thickness in a fillet weld?

For a fillet weld with equal leg lengths, the throat thickness (effective throat) is equal to the leg size multiplied by $\sin 45^\circ$, or approximately 0.707 times the leg size.

Can fillet weld size be calculated using stress analysis?

Yes, fillet weld size can be calculated by performing stress analysis on the joint to determine the forces involved, then using welding design formulas or standards to size the weld to resist those stresses safely.

What role do welding codes play in fillet weld size calculation?

Welding codes such as AWS D1.1, ISO 2553, and EN standards provide guidelines, formulas, and minimum requirements for calculating and verifying fillet weld sizes to ensure safety and compliance.

How do you measure fillet weld size on a completed weld?

Fillet weld size on a completed weld is measured by using a fillet weld gauge to measure the leg length from the root of the weld to the toe on both sides of the weld.

What is the difference between theoretical and actual fillet weld size?

The theoretical fillet weld size is the designed or specified leg length based on calculations, while the actual size is the measured leg length on the completed weld, which may vary due to welding conditions and quality.

How do load type and direction affect fillet weld size calculation?

Different load types (tensile, shear, bending) and their directions affect

the stresses on the weld. Fillet weld size calculations must consider these factors to ensure the weld can resist the specific load conditions safely.

Additional Resources

1. Welding Handbook: Fundamentals of Weld Design and Fillet Size Calculation

This comprehensive handbook covers the essential principles of welding, including detailed methods for calculating fillet weld sizes. It explains the relationship between weld size, strength, and load requirements, providing practical examples and diagrams. Ideal for engineers and welding professionals, it bridges theory and practical application in weld design.

2. Structural Welding: Fillet Weld Size and Strength Analysis

Focused on structural applications, this book delves into the analysis of fillet welds for various load conditions. It offers step-by-step procedures for determining appropriate fillet weld sizes to ensure safety and compliance with industry standards. The text includes case studies and calculation exercises to enhance understanding.

3. Weld Design and Fabrication: Calculating Fillet Weld Sizes for Optimal Performance

This book provides a thorough approach to weld design, emphasizing the importance of accurate fillet size calculations. It discusses factors affecting weld strength such as material properties, stress types, and loading scenarios. Readers will find formulas, tables, and design charts tailored for practical weld sizing.

4. Practical Guide to Weld Fillet Size Calculation and Inspection

Aimed at welding inspectors and quality control professionals, this guide offers clear instructions on measuring and verifying fillet weld sizes. It covers common calculation methods, inspection tools, and acceptance criteria based on international welding codes. The book also includes troubleshooting tips for common weld defects related to incorrect sizing.

5. Advanced Welding Techniques: Fillet Size Optimization for Structural Integrity

This advanced text explores the optimization of fillet weld sizes to enhance structural integrity and reduce material costs. It integrates finite element analysis and experimental data to validate calculation methods. Engineers will gain insights into balancing weld size, strength, and fabrication efficiency.

6. Code-Compliant Fillet Weld Design: Calculations and Applications

This book focuses on fillet weld sizing in accordance with major welding codes such as AWS, ASME, and ISO standards. It explains code requirements and provides practical examples of fillet weld calculations for different joint configurations. The clear presentation assists designers in producing compliant and reliable welds.

7. Engineering Calculations for Welding: Fillet Weld Size and Load Capacity

A detailed resource for engineers, this book covers the mathematical foundations behind fillet weld size calculations and load capacity assessments. It includes worked examples and problem sets related to bending, shear, and tensile loading. The text is suitable for both students and practicing professionals seeking a deeper understanding.

8. Welding Metallurgy and Fillet Weld Dimensions

This book links the principles of welding metallurgy with the practical aspects of determining fillet weld dimensions. It discusses how metallurgical factors influence weld strength and how these considerations affect the selection of fillet weld size. The book is valuable for metallurgists and weld designers alike.

9. Fundamentals of Fillet Weld Size Calculation: Theory and Practice

A beginner-friendly introduction to fillet weld sizing, this book explains the basic theory behind weld geometry and strength. It presents simple calculation methods, supported by illustrative examples and diagrams. Perfect for students and entry-level engineers, it lays a strong foundation for further study in weld design.

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Weld Fillet Size Calculation: A Comprehensive Guide for Engineers and Welders

This ebook provides a thorough understanding of weld fillet size calculation, a critical aspect of structural integrity and design in various engineering applications, encompassing crucial theoretical foundations, practical applications, and relevant standards. Proper fillet weld sizing ensures strength, prevents failures, and optimizes material usage, impacting project cost and safety.

Ebook Title: Mastering Weld Fillet Size Calculation: From Theory to Practical Application

Outline:

Introduction: Defining weld fillets, their types, and importance in structural design.

Chapter 1: Understanding Weld Strength and Load Transfer Mechanisms: Exploring the fundamental principles governing load distribution in fillet welds.

Chapter 2: Standard Codes and Specifications: A review of relevant international welding codes (e.g., AWS D1.1, ISO 9692) and their impact on fillet weld design.

Chapter 3: Methods for Calculating Fillet Weld Size: Detailed explanations of various calculation methods, including throat thickness, leg length, and effective throat.

Chapter 4: Factors Influencing Fillet Weld Size Selection: Analyzing factors such as material properties, joint design, loading conditions, and weld quality.

Chapter 5: Practical Application and Case Studies: Real-world examples illustrating the calculation and selection of appropriate fillet weld sizes in different scenarios.

Chapter 6: Advanced Topics in Fillet Weld Design: Exploring advanced concepts like fatigue considerations, weld distortion, and non-destructive testing (NDT) techniques.

Chapter 7: Software and Tools for Weld Design: Reviewing available software and tools that aid in fillet weld size calculation and optimization.

Conclusion: Summarizing key concepts and emphasizing the importance of accurate fillet weld size calculation for ensuring structural integrity and safety.

Detailed Explanation of Outline Points:

Introduction: This section establishes the context by defining what a fillet weld is, its various types (e.g., equal leg, unequal leg), and its significance in ensuring the structural integrity of welded joints. It will also briefly introduce the importance of accurate calculation.

Chapter 1: Understanding Weld Strength and Load Transfer Mechanisms: This chapter delves into the mechanics of how loads are transferred through a fillet weld. It will explain concepts like shear stress, tensile stress, and the effective throat, crucial for understanding the weld's capacity.

Chapter 2: Standard Codes and Specifications: This crucial section examines the relevant welding codes and standards (AWS, ISO, EN) that dictate the acceptable methods and procedures for calculating fillet weld sizes. Understanding these standards is vital for compliance and safety.

Chapter 3: Methods for Calculating Fillet Weld Size: This chapter presents the different formulas and approaches used to determine the necessary fillet weld size. It will cover calculations based on throat thickness, leg length, and effective throat, clarifying the relationships between these parameters.

Chapter 4: Factors Influencing Fillet Weld Size Selection: This section highlights the numerous factors impacting fillet weld design, including material properties (yield strength, tensile strength), joint configuration (butt joint, lap joint, tee joint), type of loading (static, dynamic, fatigue), and the quality of the weld itself (defects, porosity).

Chapter 5: Practical Application and Case Studies: This chapter presents real-world examples of fillet weld size calculations across different engineering applications. Case studies will illustrate the application of the methods described previously and showcase how to handle various scenarios.

Chapter 6: Advanced Topics in Fillet Weld Design: This chapter explores more complex aspects, such as fatigue life prediction for fillet welds under cyclic loading, methods to minimize weld distortion, and the role of Non-Destructive Testing (NDT) in verifying weld quality and soundness.

Chapter 7: Software and Tools for Weld Design: This section examines commercially available software and tools that can simplify and automate the fillet weld size calculation process. It will highlight the advantages and limitations of such software.

Conclusion: The conclusion summarizes the key takeaways from the ebook, emphasizing the

importance of accurate fillet weld sizing in ensuring the safety and reliability of welded structures. It reinforces the practical implications of miscalculations and the need for adherence to relevant standards.

9 Unique FAQs

1. What is the difference between leg length and throat thickness in a fillet weld? Leg length is the distance from the weld root to the toe of the weld, while throat thickness is the shortest distance from the weld root to the fusion line. Throat thickness is typically used in strength calculations.
2. How does the material's yield strength affect fillet weld size? Higher yield strength materials require smaller fillet welds to achieve the same strength compared to lower yield strength materials.
3. What is the significance of the weld factor in fillet weld calculations? The weld factor accounts for the imperfections and variations in the weld metal, reducing the theoretical strength of the weld.
4. What are the common types of fillet welds? Common types include equal leg and unequal leg fillet welds, depending on the leg lengths.
5. Can I use the same fillet weld size for all types of joint configurations? No, the optimal fillet weld size depends heavily on the joint configuration (e.g., lap joint, tee joint, butt joint) and the applied loading.
6. What are some common causes of fillet weld failures? Fillet weld failures can result from insufficient weld size, poor weld quality (porosity, cracks), improper loading conditions, or material defects.
7. What role does non-destructive testing (NDT) play in fillet weld quality control? NDT techniques like radiographic testing (RT) and ultrasonic testing (UT) are used to detect internal flaws in the welds that might compromise their strength.
8. What software packages are commonly used for fillet weld design and analysis? Several Finite Element Analysis (FEA) software packages and specialized welding design software can assist in weld design and analysis.
9. Are there any limitations to the formulas used for fillet weld size calculations? Yes, the formulas are based on simplified assumptions and may not always accurately reflect the complex stress distribution in a real weld. Factors such as weld geometry and residual stresses can influence the actual strength.

9 Related Articles:

1. Weld Joint Design and Selection: This article discusses various weld joint configurations and their suitability for different applications, influencing the choice of fillet weld size.
2. AWS D1.1 Structural Welding Code – A Deep Dive: This article focuses on the key provisions of the widely used AWS D1.1 structural welding code, including the requirements for fillet weld design.
3. Fatigue Analysis of Welded Joints: This article explores the principles of fatigue failure in welded structures, specifically concerning fillet welds under cyclic loading.
4. Understanding Weld Metal Properties: This article explains the mechanical properties of weld metal and how they differ from the base metal, impacting fillet weld design.
5. Weld Distortion and its Mitigation Techniques: This article discusses the causes and effects of weld distortion and methods to minimize it during the welding process.
6. Non-Destructive Testing (NDT) of Welds: This article provides an overview of different NDT techniques used to inspect welds for defects and ensure quality.
7. Introduction to Welding Metallurgy: A primer on the metallurgical aspects of welding, providing a foundation for understanding weld metal behavior and properties.
8. Advanced Welding Techniques for improved joint strength: Exploring modern welding techniques that can improve the strength and quality of fillet welds.
9. Weldability of Different Metals and Alloys: This article explores the weldability characteristics of various metals and alloys, guiding the selection of appropriate welding procedures and parameters.

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copying a few joint configurations in a drawing will not suffice. All-embracing and readable, *Designing Weldments* delivers a deeper understanding of many design factors that play a critical role in the design. The book clarifies welding design principles and applications. With this reference in hand, designers will have expert knowledge to consider very early on in the project, the implications of the choice of what type of weld to use for joining structural members, and how the component is made. The author explains the many welding techniques developed over the years, as well as some of which are still evolving. The reader will also find in this book: Rules of thumb for saving time and money in the design phase of a project. An insider's view for choosing the proper welding approach to ensure the overall strength of a structure. Offers structural engineers a deeper understanding of the weld within their structures. Clarifies welding design principles and applications, limiting the necessity to redesign the structure. Audience The intended market for this book is professionals working on the infrastructural projects in shipbuilding, construction of buildings, bridges, offshore platforms, wind towers for renewable energy, and other structures that join plates, pipes, and pipelines in power plants, manufacturing, and repair.

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weld fillet size calculation: *Architectural Graphic Standards* The American Institute of Architects, 2007-03-30 Since 1932, the ten editions of *Architectural Graphic Standards* have been referred to as the architect's bible. From site excavation to structures to roofs, this book is the first place to look when an architect is confronted with a question about building design. With more than 8,000 architectural illustrations, including both reference drawings and constructible architectural details, this book provides an easily accessible graphic reference for highly visual professionals. To celebrate seventy-five years as the cornerstone of an industry, this commemorative Eleventh Edition

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a plan for compliance. The book covers American Water Works Association standards where they are applicable. - Updates to major codes and standards such as ASME B31.1 and B31.12 - New methods for calculating stress intensification factor (SIF) and seismic activities - Risk-based analysis based on API 579, and B31-G - Covers the Pipeline Safety Act and the creation of PhMSA

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weld fillet size calculation: Computational Welding Mechanics Lars-Erik Lindgren, 2014-01-23 Computational welding mechanics (CWM) provides an important technique for modelling welding processes. Welding simulations are a key tool in improving the design and control of welding processes and the performance of welded components or structures. CWM can be used to model phenomena such as heat generation, thermal stresses and large plastic deformations of components or structures. It also has a wider application in modelling thermomechanical and microstructural phenomena in metals. This important book reviews the principles, methods and applications of CWM. The book begins by discussing the physics of welding before going on to review modelling methods and options as well as validation techniques. It also reviews applications in areas such as fatigue, buckling and deformation, improved service life of components and process optimisation. Some of the numerical methods described in the book are illustrated using software available from the author which allows readers to explore CWM in more depth. Computational welding mechanics is a standard work for welding engineers and all those researching welding processes and wider thermomechanical and microstructural phenomena in metals. - Highlights the principles, methods and applications of CWM - Discusses the physics of welding - Assesses modelling methods and validation techniques

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survival probability is acceptable. The latter is achieved by the use of appropriate partial safety factors. This document has been prepared as the result of an initiative by Commissions XIII and XV of the International Institute of Welding (IIW).

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in steel moment-frame buildings following an earthquake, evaluating the damaged buildings to determine their safety in the postearthquake environment, and repairing damaged buildings. FEMA-353 - Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications. This publication provides recommended specifications for the fabrication and erection of steel moment frames for seismic applications. The recommended design criteria contained in the other companion documents are based on the material and workmanship standards contained in this document, which also includes discussion of the basis for the quality control and quality assurance criteria contained in the recommended specifications. The information contained in these recommended design criteria, hereinafter referred to as Recommended Criteria, is presented in the form of specific design and performance evaluation procedures together with supporting commentary explaining part of the basis for these recommendations.

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Dieter Radaj, C M Sonsino, W Fricke, 2006-10-30 Local approaches to fatigue assessment are used to predict the structural durability of welded joints, to optimise their design and to evaluate unforeseen joint failures. This standard work provides a systematic survey of the principles and practical applications of the various methods. It covers the hot spot structural stress approach to fatigue in general, the notch stress and notch strain approach to crack initiation and the fracture mechanics approach to crack propagation. Seam-welded and spot-welded joints in structural steels and aluminium alloys are also considered. This completely reworked second edition takes into account the tremendous progress in understanding and applying local approaches which has been achieved in the last decade. It is a standard reference for designers, structural analysts and testing engineers who are responsible for the fatigue-resistant in-service behaviour of welded structures. - Completely reworked second edition of a standard work providing a systematic survey of the principles and practical applications of the various methods - Covers the hot spot structural stress approach to fatigue in general, the notch stress and notch strain approach to crack initiation and the fracture mechanics approach to crack propagation. - Written by a distinguished team of authors

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Analysis of Welded Structures: Residual Stresses, Distortion, and their Consequences encompasses several topics related to design and fabrication of welded structures, particularly residual stresses and distortion, as well as their consequences. This book first introduces the subject by presenting the advantages and disadvantages of welded structures, as well as the historical overview of the topic and predicted trends. Then, this text considers residual stresses, heat flow, distortion, fracture toughness, and brittle and fatigue fractures of weldments. This selection concludes by discussing the effects of distortion and residual stresses on buckling strength of welded structures and effects of weld defects on service behavior. This book also provides supplementary discussions on some related and selected subjects. This text will be invaluable to metallurgists, welders, and students of metallurgy and welding.

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design stage.

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for the undergraduate students of mechanical engineering and allied branches, this book serves as a bridge between the study of the basic processes and their application in production industries. This book covers two similar fundamental processes—foundry and welding—in a single volume. The chapters of the book are grouped in seven modules. A separate module is devoted to introduce the preliminaries of the two areas namely casting and joining processes. Miscellaneous welding and allied processes, including the modern methods and thermal cutting, conventional sand mould casting, special and modern casting methods, conventional metal joining processes and theory of solidification of metal, its metallurgy, defects in castings and casting design procedure are covered in the book. The theory of each process is explained with the help of simple line sketches which can be easily reproduced by a student at the time of examination. Enough worked out examples and problems are given for practice, especially in the design areas. At the end of each chapter, sufficient number of review questions are given as exercise.

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