NUMERICAL VALIDATION OF FIRE-EFFECTED REINFORCED CONCRETE BEAM

Submitted by

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A Thesis Submitted to the Department of Civil Engineering, Daffodil International University in Partial Fulfillment of the Requirements for the Degree Of
Bachelor of Science in Civil Engineering

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June 2024

Certification

This is to certify that this project and thesis entitled **"Numerical Validation of Fire-Effected Reinforced Concrete Beam"** is done by the following students under my direct supervision. This work has been carried out by them in the laboratories of the Department of Civil Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering. The presentation of the work was held on 06th June 2024.

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The thesis entitled **"Numerical Validation of Fire-Effected Reinforced Concrete Beam"** submitted by **Md. Abu Sayed**, #ID No: 201-47-277, Session: Spring 2020 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Civil Engineering** on 06th June 2024.

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DEDICATION

I dedicate this thesis to my beloved parents, sisters, and brothers, whose unwavering support and generosity have been fundamental to my academic journey. Your belief in my abilities has been the driving force behind my endeavors.

A heartfelt thank you goes to my dear Mother for her steadfast assistance, encouragement, and confidence, which have been pivotal to my progress. Your sacrifices and guidance have profoundly shaped my character, and I acknowledge our shared role in this achievement. Your guidance has been my guiding light.

I am indebted to my family for their love, empathy, and patience, which have provided me with steadfast support. Your unwavering belief in my aspirations has spurred me on to significant accomplishments.

I extend sincere appreciation to my educators and mentors whose wisdom and guidance have enriched my scholarly pursuits. Your dedication to fostering knowledge and nurturing intellectual curiosity has been invaluable.

This thesis is dedicated to those who have played integral roles in my life, actively contributing to my personal growth and achievements. I am grateful for your consistent presence as a perpetual source of motivation and assistance.

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ACKNOWLEDGEMENT

I begin by thanking ALLAH, the source of all knowledge and power, for giving me the perseverance and resilience required to finish this thesis.

I want to express my genuine gratitude to **Md. Mehedi Hassan Bhuiyan**, **Lecturer** of the **Department of Civil Engineering**, for his guidance and support as my thesis and thesis supervisor. The individual's unwavering commitment, assistance, and direction

have played a crucial role in the success of this activity. I express my gratitude for his invaluable counsel and support, which have greatly helped the successful completion of this thesis.

I also want to thank **Dr. Mohammad Hannan Mahmud Khan**, the **head of the Department of Civil Engineering and assistant professor**, for all his assistance, encouragement, and support.

I want to express my heartfelt gratitude to **Ahmed Mohamed Omar** for his outstanding support of the Abaqus Model. This assistance greatly expedited the completion of my thesis project. The individual's benevolence and will to assist have been crucial to my educational path.

We extend our heartfelt gratitude and affection to our treasured family.

Their unfailing support, inspiration, and encouragement have been indispensable throughout my educational journeys at this University.

ABSTRACT

This study aims to validate experimental test results of post-fire reinforced concrete beams within a finite element environment while identifying temperature-related and structural response parameters. The comparison between finite element simulations and experimental findings demonstrated remarkable consistency. Through multiple trials, a viscosity range for 0.001 to 0.000001 was examined, with a viscosity of 0.000001 yielding satisfactory outcomes for the beam. Additionally, analysis revealed that a dilation angle of 31 degrees provided satisfactory results, with a range of 20 to 31 degrees being reliable and consistent. Mesh sizes ranging from 20 mm to 50 mm were utilized, with a 25 mm mesh size identified as the most suitable through finite element analysis. The validation approach demonstrated good agreement with experimental test results, particularly concerning thermocouple temperature during the fire and post-fire capacity of the reinforced concrete beam. This comprehensive validation process enhances confidence in the accuracy and reliability of finite element simulations for assessing post-fire behavior in reinforced concrete structures.

CHAPTER 1
INTRODUCTION

1.1 General

The frequency of fire incidents in Bangladesh's metropolitan regions has become a significant concern in recent years. The escalating prevalence of urban locales prone to fire hazards poses a significant threat to both property and public welfare. Cities characterized by high population density, such as Dhaka and Chittagong, are particularly susceptible due to their often underdeveloped infrastructure and the prevalence of informal settlements. The transient nature of housing, constrained access to utilities, and narrow thoroughfares within these communities further exacerbate their vulnerability to fires. Despite the startlingly high number of fire accidents, especially in marginalized communities, there is a lack of comprehensive information and no focus on public awareness.

The increased vulnerability arises from various factors, including densely populated makeshift housing areas, substandard infrastructure, poor living conditions, and ineffective enforcement of safety regulations. These factors contribute to an increased risk of fires, which may inflict substantial damage to towns and communities.

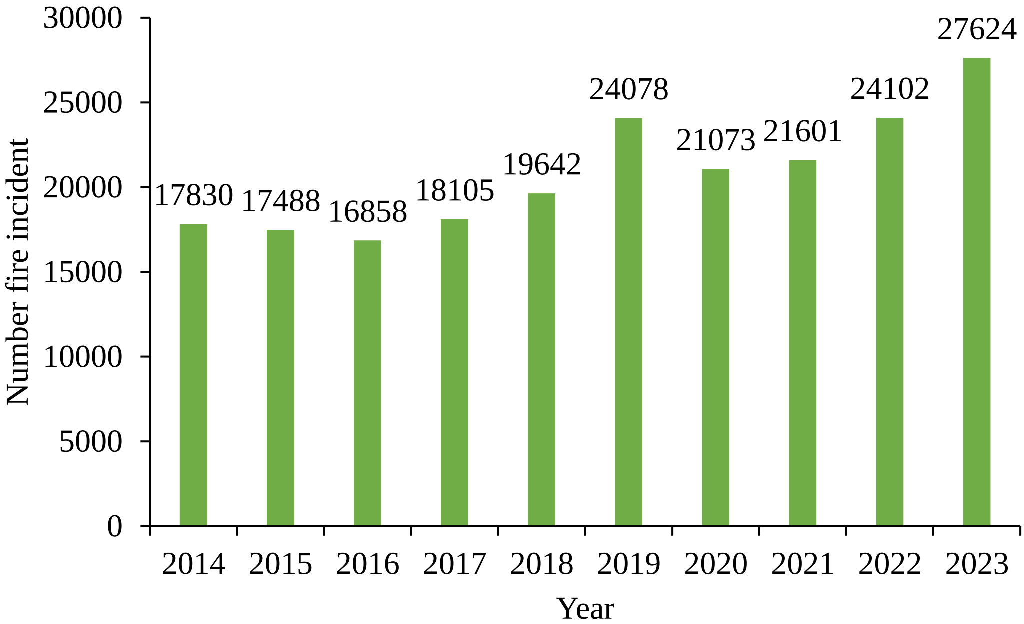


Figure 1.1: Number of fires in the last ten years.

Figure 1.1: (Ahmadul Hassan, 2024) (Saad, 2020) (Hossain, 2024) presents a pie chart illustrating the distribution of fires over the past decade. The entirety of the chart represents the total number of fires recorded over the specified period. Each slice within

the chart corresponds to a particular year within the past ten years, with the size of each slice proportional to the number of fires occurring in that specific year. This visual representation offers a concise and easily interpretable overview of how fire incidents have been distributed across the years, allowing viewers to quickly grasp the relative contribution of each year to the total number of fires within the timeframe.

Fire Service & Civil Defense (FSCD) reports that 2,603 structures in the capital are at risk of catching fire. There are 1,106 shopping complexes among the structures. Schools, hospitals, apartments, and media outlets are among the facilities that pose a risk. Inspections between 2018 and 2023 created this list of structures that pose a risk (Ahmadul Hassan, 2024).

Among the most commonly used building materials, concrete resists fire effectively. Because of its low heat conductivity and non-combustibility, fire takes a long time to affect its structural load-bearing ability, and it also acts as a fire barrier. It is frequently used to strengthen and protect steel from fire since it is substantially more fire-resistant than steel. It is made up of cement and aggregate, and both the kind and quantity of aggregate utilized might change. Between 60 and 80 percent of the volume of concrete can be made with aggregate. The specific fire resistance characteristics vary according to the kind and quantity of aggregate utilized. In general, natural aggregates don't work as well. The moisture in the aggregate can expand when heated, causing the concrete to harden after prolonged exposure (Homer, 2022).

In structures, temperatures during a fire can rise to 1100°C, and in tunnels, they can even reach 1350°C. When concrete structural elements are exposed to high temperatures, their strength is reduced and, more importantly, the bond between the aggregate and binding materials is broken, resulting in significant losses in the structural capacity of the concrete.

When heated, concrete expands, and when cooled, it contracts. The rate at which concrete expands or contracts in response to temperature variations is determined by the coefficient of thermal expansion. High temperatures have the potential to cause severe thermal expansion in concrete components, which might result in structural distress and cracking.

The mechanical characteristics of concrete, such as its strength and durability, are influenced by temperature. Concrete generally loses strength as the temperature rises. This is caused by things like microstructure changes, bond strength loss between aggregate and cement paste, and heat cracking. High temperatures have the potential to accelerate chemical processes in concrete, resulting in a gradual degradation of its characteristics.

The inherent features of concrete, such as its low heat conductivity and high thermal mass, make it a material that is often considered to be fire-resistant. Prolonged exposure to high temperatures, however, may cause its structural integrity to be compromised. The rate at which the temperature rises and the duration of exposure are critical factors in assessing the level of concrete damage during a fire.

1.2 Objective

The objective of this study is to validate the experimental test results (Ankit Agrawal, 2016) of post-fire reinforced concrete beams within a finite element environment. Additionally, this study aim to identify temperature-related and structural response parameters (such as emissivity, surface film conditions, and concrete damage parameters) that contribute to verifying the experimental results in the finite element analysis.

1.3 Summary

The paper discusses the increasing fire incidents in urban Bangladesh, emphasizing the vulnerability of densely populated areas with poor infrastructure. It highlights the importance of concrete’s fire resistance and sets the objective to assess the behavior of fire-damaged reinforced concrete beams.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Literature reviews serve as integral components within scholarly articles and research papers, offering comprehensive insights into various perspectives on a given topic. Instead of being in a vacuum, they serve as vital resources that help researchers make their way through the vast amount of material relevant to their field of study. To clarify the function that literature reviews serve in allowing comprehensive analyses, developing analytical frameworks, and encouraging interaction with conceptual frameworks, the article presents an overview of the importance and technique of literature reviews. Through synthesizing diverse viewpoints, literature reviews contribute to academic discourse, evaluate existing knowledge, and broaden discussions within specific domains. This paper underscores the importance of literature reviews in enhancing research processes and promoting well-informed scholarly inquiry.

2.2 Overview

The author has highlighted the articles that are important for their future analysis of the paper. This has greatly benefited the author in their research. Every writer needs to gain knowledge from various articles or papers when conducting their research or writing. This helps them to have a better understanding of the subject that they are analyzing or writing about. It is also essential for the writer to convey the significance of their writing to their readers, which is the main focus of this chapter.

2.3 Literate review

Offering a thorough synopsis of all the publications and research papers analyzed during the review process, this part gives readers a comprehensive overview of the topic.

(Dafni Pantousa, 2022) The paper presents a comprehensive numerical investigation into the post-fire performance of steel columns, particularly in the context of seismic activity. The primary objective is to assess the safety of reusing steel structures after fire exposure, especially in areas prone to earthquakes. The findings reveal that steel structures designed to current seismic codes can withstand fire without significant structural damage and may be repaired for reuse. The research utilizes sophisticated finite element models validated against experimental data to predict the behavior of steel beams and columns at elevated temperatures. Results indicate that these models can accurately simulate the post-fire cyclic behavior of columns, considering residual deformations and material properties. The study concludes that the post-fire damage significantly impacts the cyclic behavior of columns, emphasizing the importance of evaluating the post-fire integrity of steel structures before deeming them safe for reuse in seismic zones. This research contributes valuable insights into the performance-based fire engineering approach, advocating for a shift from prescriptive to performance-based fire safety design in buildings.

(Venkatesh K. R. Kodur, 2020) The paper titled "Estimating Postfire Residual Capacity of Heavily Damaged Concrete Members" by Venkatesh K. R. Kodur and Ankit Agrawal presents a comprehensive five-step approach for assessing the residual capacity of concrete structures after severe fire damage. The objectives are to utilize limited information from the fire event, such as fire timeline and peak temperatures, to estimate fire severity and the subsequent temperature-induced damage to structural members. The findings reveal that significant residual capacity is often retained in concrete structures post-fire. However, this capacity is highly variable and dependent on factors like fire severity and structural conditions during exposure. The results from the study underscore the importance of detailed classification of temperature-induced damage and the necessity of both simplified and advanced analysis methods for accurate residual capacity estimation. The decision-making process for retrofitting or replacement strategies is informed by this assessment, which is crucial for ensuring the safe occupancy of fire-damaged structures and their potential service life restoration. This paper provides a pragmatic and methodical framework for engineers and practitioners in the field of structural fire safety and resilience.

(Bin Cai1, 2020) The paper focuses on the residual flexural capacity of post-fire reinforced concrete (RC) beams. The objectives were to analyze the post-fire performance using finite element simulation and to develop a calculation method for evaluating the flexural capacity after fire exposure. Findings revealed that factors such as concrete cover thickness, reinforcement ratio, fire exposure time, and sides exposed to fire significantly affect fire resistance. The research utilized ABAQUS software for finite element analysis (FEA), validating the model with fire test results. An improved section method was proposed, offering a more accurate calculation of flexural capacity post-fire compared to the Eurocode 500°C isotherm method. The decision from this study provides a theoretical framework that can be used for assessing the structural integrity of RC beams after fire, contributing to safer structural design and evaluation in fire scenarios.

(Bin Cai, 2019) The paper presents a novel reliability analysis approach for assessing the flexural capacity of post-fire reinforced concrete (RC) beams retrofitted with carbon fiber-reinforced polymers/plastics (CFRPs). The study utilizes a comprehensive method involving heat transfer analysis in ABAQUS, followed by a section method to calculate residual flexural capacity, and finally, a Monte Carlo method for reliability analysis. Key findings indicate that fire exposure time, concrete cover thickness, and CFRP usage significantly influence the reliability of RC beams' flexural capacity post-fire. Results from finite element simulations and theoretical analyses align with experimental data, validating the proposed approach's effectiveness. The decision derived from this research underscores the importance of CFRP reinforcement in enhancing post-fire RC beams' structural integrity, suggesting that increasing concrete cover thickness can effectively slow down the deterioration of post-fire reliability in RC beams. This study's outcomes provide a robust framework for evaluating and ensuring the safety of fire-damaged structures rehabilitated with CFRPs.

(Rui Sun, 2018) The paper presents a numerical approach for predicting the mechanical behavior of reinforced concrete (RC) beams exposed to fire. Utilizing a two-dimensional finite element model for thermal behavior and a one-dimensional spectral numerical model for the mechanical response, the study integrates both models to efficiently simulate the thermomechanical behaviors of RC beams. The results align with experimental data, demonstrating the model's capability to accurately predict the structural performance of RC beams under fire exposure. This approach significantly reduces computational burden compared to conventional methods, offering a promising tool for assessing fire damage in RC structures. The findings suggest potential for practical applications in structural fire safety analysis.

(Chang-Jiu Jiang, 2018) The paper presents an experimental investigation into the residual shear capacity of fire-damaged reinforced concrete (RC) frame beams and cantilevers. The study's objectives were to understand the post-fire shear properties, which are less explored compared to flexural properties, and to develop a simplified evaluation process for assessing the shear capacity of fire-damaged RC beams. The findings revealed that both the shear capacity and stiffness of RC beams degrade significantly after exposure to fire. The experimental results showed that the diagonal cracks in frame beams with fewer stirrups were more concentrated and wider. A simplified evaluation method was proposed based on the experimental data, which proved to be accurate in predicting the residual shear capacity of fire-damaged RC beams. The decision from this study emphasizes the importance of considering shear span ratio, concrete slab presence, and stirrup spacing when evaluating post-fire damage, leading to more informed repair and retrofitting strategies for fire-damaged RC structures.

(Venkatesh Kodura, 2017) The paper investigates the residual capacity of reinforced concrete (RC) columns post-fire exposure. It reveals that despite high-temperature exposure, RC columns retain significant structural integrity. The study conducted residual capacity tests on two RC columns subjected to controlled fire scenarios simulating building fires. The columns were monitored for temperature, deformation, and spalling during the fire and subsequently tested for failure post-cooling. Findings indicate that columns maintain a considerable portion of their original strength, with residual capacities close to ACI 38 design capacity but significantly lower than the un-factored nominal capacity. This discrepancy is attributed to safety factors in design codes and actual material strengths. The research underscores the importance of realistic fire scenarios, including cooling phases, for accurate fire performance assessment of RC members and informs repair and retrofitting strategies post-fire incidents. The study's outcomes contribute to developing a finite element model for predicting the residual response of fire-damaged RC columns, enhancing structural fire resilience.

(Xiuling Li, 2017) The paper presents the thermal and mechanical properties of high-performance fiber-reinforced cementitious composites (HPFRCCs) after exposure to high temperatures. Objectives include assessing thermal conductivity, specific heat, compressive strength, tensile strength, ductility, and density of HPFRCCs with varying mix proportions when subjected to temperatures up to 800°C. Findings reveal that thermal and mechanical properties significantly depend on temperature and mix proportions due to physicochemical reactions at elevated temperatures. Results indicate a decrease in thermal conductivity and specific heat with increasing temperature, while the compressive strength initially increases up to 200°C and then diminishes. The study concludes that optimizing mix proportions can enhance HPFRCCs' thermal and mechanical performance, making them suitable for fire-resistant applications and high-temperature environments. This research contributes to the development of sustainable buildings with improved fire resistance and durability.

(V.K.R. Kodur A. A., 2017) The paper investigates the impact of temperature-induced bond degradation on the fire response of reinforced concrete (RC) beams. The study employs a finite element model in ABAQUS to simulate the fire exposure of RC beams, considering the interfacial bond degradation between concrete and reinforcing steel. The research focuses on the influence of temperature-dependent local bond stress-slip relations on the fire resistance of both normal-strength and high-strength RC beams. Findings reveal that the interfacial bond significantly affects the extent of strength degradation and deflections in RC beams under fire, leading to lower fire resistance, especially when rebar temperatures exceed 400°C. The results challenge the current practice of assuming a perfect bond in fire resistance analysis, suggesting that such assumptions may be unconservative. The study concludes that incorporating bond degradation is crucial for accurate fire resistance evaluation of RC structures, particularly for beams reinforced with smooth rebars and subjected to high temperatures. This highlights the need for revised guidelines that account for bond degradation in fire resistance analysis.

(Wei Wang, 2017) The paper presents the carbonation resistance of fly ash concrete under various stress states, high temperatures, and fly ash content to provide insights for the design and analysis of concrete structures. It reveals that tensile stress increases carbonation depth, while a certain level of compressive stress can minimize it. The study also finds that high temperatures significantly reduce both the compressive strength and carbonation resistance of concrete, with fly ash concrete being more affected than ordinary concrete. The results indicate that a combination of stress, high temperature, and high fly ash content markedly diminishes the carbonation resistance of concrete. Consequently, the paper suggests that special anti-carbonation durability measures should be considered in the design of fly ash concrete structures to ensure longevity and sustainability. These findings contribute to the understanding of concrete durability under complex conditions, emphasizing the need for careful consideration of environmental and material factors in construction.

(Venkatesh Kodur D. H., 2017) The study presented in the paper investigates the residual capacity of reinforced concrete (RC) columns after fire exposure. It reveals that despite significant fire damage, RC columns retain considerable structural integrity. The research involved testing two RC columns under controlled fire scenarios, followed by post-cooling load tests to assess residual strength. Findings indicate that columns maintain up to 34% of their nominal capacity post-fire, emphasizing the importance of considering realistic fire conditions, including cooling phases, for accurate fire performance assessment. The study underscores the resilience of RC structures against fire and informs repair and retrofitting strategies, contributing to safer building designs.

(Mousa, 2015)The paper investigates the flexural behavior and ductility of High Strength Concrete (HSC) beams with varying tension reinforcement lap splice lengths. The study’s objectives were to understand the impact of splice length, bar diameter, transverse reinforcement, anchor shape, and concrete cover on the beams’ response under static loading. The research utilized eighteen concrete beams with different configurations, subjected to mid-span loading to simulate real-world conditions. Findings revealed that appropriate transverse reinforcement could significantly enhance ductility, approaching 9% of reference beams without splices. The results indicated that beams with shorter splice lengths exhibited sudden, violent splitting failures, while longer splices led to flexural failure modes. The study concluded that by optimizing splice length and reinforcement, particularly with the inclusion of transverse stirrups and hooked bar ends, the bond strength and ductility of HSC beams could be substantially improved, contributing to safer and more reliable concrete structures.

(Agrawal, 2015) The literature review presented in the paper "Critical Factors Governing the Residual Response of Reinforced Concrete Beams Exposed to Fire" by

Kodur and Agrawal aims to investigate the critical factors influencing the residual response of fire-exposed RC beams. The objectives include studying the effects of material properties, fire intensity, loading conditions, and beam size on post-fire residual capacity and deformations. The findings reveal that factors such as axial restraint, load level during fire exposure, and beam size significantly impact the residual response of RC beams. Results from parametric studies demonstrate the importance of considering these factors in assessing the structural performance of fire-exposed RC beams. Ultimately, the study provides valuable insights for enhancing the design and assessment of reinforced concrete structures under fire conditions.

(W.Y. Gao 1, 2013) The paper presents a comprehensive finite element (FE) model for simulating the thermal and mechanical behavior of reinforced concrete (RC) beams under fire exposure. Focusing on the bond-slip behavior between steel and concrete, the model offers more accurate predictions of deflection in fire-damaged RC beams. Validation against experimental data confirms the model's precision, particularly in capturing stress distribution and local responses. This FE model serves as a robust tool for performance-based fire safety design, enabling detailed parametric studies and the development of simplified design rules for RC beams in fire scenarios.

(V.K.R. Kodur B. Y., 2013) The research aimed to create a simplified technique using statistical regression analysis to forecast temperatures in reinforced concrete members under standard fire conditions. Through varying parameters in finite element analysis, data was collected to establish regression equations for temperature prediction. The study demonstrated the accuracy of the proposed method in estimating temperatures in fire-exposed concrete elements, with mean errors falling within acceptable ranges for different concrete types and heat transfer scenarios. The results highlighted the reliability of the regression equations in critical temperature-sensitive areas and their slightly conservative nature in other regions. This study presents a valuable tool for evaluating the fire resistance of reinforced concrete structures, providing an effective and practical approach for temperature prediction during fire exposure.

(W.Y. Gao, 2013) The objective of the paper was to develop a comprehensive finite element model to simulate the behavior of reinforced concrete beams exposed to fire accurately. By incorporating temperature-dependent bond-slip behavior at the steel-to-concrete interface, the model aimed to improve predictions of beam deflection. The findings revealed that the FE model provided close agreement with experimental results for temperature distribution and mid-span deflections during fire exposure. The results demonstrated the validity and accuracy of the proposed model, especially when considering the temperature-dependent local bond-slip behavior. This study emphasizes the importance of including interfacial bond-slip effects in predicting the fire performance of RC beams, leading to more reliable structural assessments and decision-making in fire safety engineering.

(Khaliq, 2012) This paper focuses on the performance characterization of high-performance concretes (HPC) under fire conditions. HPCs, such as high-strength concrete (HSC), self-consolidating concrete (SCC), and fiber-reinforced concrete (FRC), are increasingly used in infrastructure for their superior properties. However, their fire resistance is less understood, particularly concerning fire-induced spalling and rapid strength degradation at high temperatures. The study aims to fill this knowledge gap through experimental and numerical analyses. It reveals that while HPCs share thermal properties with conventional concrete, their mechanical properties deteriorate more severely under heat. The inclusion of fibers and 35° bent ties in HPCs can significantly mitigate spalling and enhance fire resistance5. The research extends a macroscopic finite element model to include tie configuration effects, validated against experimental data6. This comprehensive approach offers a methodology to evaluate and improve the fire response of HPC columns, contributing to safer structural designs in fire-prone environments.

(E.G. Choi, 2011) The paper presents a finite element (FE) model for simulating the thermal and mechanical behavior of reinforced concrete (RC) beams under fire exposure. Focusing on the bond-slip behavior between steel and concrete, the model aims to enhance performance-based fire safety design. Validation against experimental data confirms its accuracy in predicting deflection and stress distribution in RC beams during fire, offering insights into local responses and failure mechanisms. This FE model serves as a tool for both direct design applications and parametric studies to develop simplified design rules, marking a significant advancement in the field of fire safety engineering.

(Venkatesh Kodur F. W., 2011) The paper investigates the thermal properties of various high-strength concretes (HSC) at elevated temperatures, crucial for assessing fire response in structures. It compares specific heat, thermal conductivity, and expansion across HSC, self-consolidating concrete (SCC), and fly ash concrete (FAC) from 20–800°C. The study also examines the impact of steel, polypropylene, and hybrid fibers on these properties. Findings reveal that SCC exhibits higher thermal conductivity, specific heat, and expansion than HSC and FAC within the tested range. The data aids in formulating simplified relationships for thermal properties as a function of temperature, providing valuable input for evaluating concrete structures' fire response56. The research underscores the variation in fire resistance among different concrete types, with implications for their use in fire-prone environments. The outcomes contribute to a deeper understanding of material behavior under fire conditions, influencing design and safety protocols in civil engineering.

(Structures, 2010) The paper titled “High-Temperature Properties of Steel for Fire Resistance Modeling of Structures” aims to enhance the understanding of steel’s behavior under high temperatures, which is crucial for fire resistance assessment in structural engineering. It scrutinizes the constitutive relationships for steel at elevated temperatures as outlined in American and European standards, juxtaposing them with experimental outcomes. The findings reveal significant discrepancies between the standard models and experimental data, particularly in the mechanical and deformation properties of steel, which are pivotal for accurate fire response modeling. The results underscore the substantial impact of high-temperature creep, often overlooked in constitutive models, on the fire response of steel structures. Consequently, the study advocates for the integration of appropriate constitutive models that account for high-temperature creep in the performance-based design for fire resistance. This would enable more realistic and reliable predictions, fostering the adoption of rational approaches in the fire engineering of steel structures.

(V. K. R. Kodur, 2010) The objective of the paper was to investigate the effect of fire on concrete structures, particularly focusing on the behavior of high-performance concrete (HPC) in fire conditions. The study aimed to address the challenges posed by the increasing use of HPC in buildings, tunnels, and bridges, which have shown a greater tendency to explosively spall when exposed to fire. The findings highlighted the deficiencies in traditional prescriptive methods of design for fire resistance and emphasized the need for performance-based structural analysis and design approaches. The results underscored the importance of considering factors such as mix proportions, aggregate type, and thermal stability of concrete in fire scenarios. As a decision, the paper advocated for the wider acceptance and implementation of performance-based methods in assessing and designing concrete structures for fire resistance to mitigate the risks associated with high-performance concrete in fire incidents.

(Kodur M. B., 2009) The study aimed to analyze the behavior of normal-strength concrete (NSC) and high-strength concrete (HSC) beams under realistic fire, loading, and restraint conditions using experimental and numerical methods. Results indicated that factors such as concrete strength, fire scenario, support conditions, and load levels have a significant influence on the fire response of reinforced concrete (RC) beams. The outcomes from fire tests were utilized to validate a macroscopic finite-element model capable of predicting the behavior of NSC and HSC beams under varying fire, loading, and restraint scenarios. This research provides valuable insights into enhancing the fire resistance of RC beams and improving design and construction practices for better performance under fire exposure. The decision to validate the numerical model with experimental data highlights the importance of accurately predicting the behavior of RC beams in fire conditions to ensure the safety and resilience of structures.

(Nassif, 2005) The paper investigates the postfire stress-strain behavior of concrete, which is crucial for redesigning fire-damaged structures. Experiments revealed that heating beyond 320°C increases strain at ultimate stress, with quenching exacerbating strength loss and strain. The study concludes that exposure characteristics, like the cooling method, significantly influence postfire structural behavior. These insights are vital for assessing fire-damaged concrete's load-bearing capacity, informing repair strategies, and enhancing structural resilience against future fire incidents.

(Kodur & Sultan, 2003) The paper investigates the thermal properties of high-strength concrete (HSC) at elevated temperatures, which is crucial for fire resistance calculations in structural engineering. The study, conducted by the National Research Council of Canada, focuses on the thermal conductivity, specific heat, thermal expansion, and mass loss of HSC, considering variables like aggregate type and steel fiber reinforcement. Findings reveal that aggregate type significantly impacts thermal properties, with carbonate aggregate enhancing fire resistance. Steel fiber reinforcement shows minimal effect on thermal properties. The research contributes to developing fire resistance design guidelines for HSC, aiding in the prediction of structural behavior under fire exposure3. These insights are pivotal for ensuring the safety and integrity of HSC structures in fire incidents, marking a significant advancement in fire safety engineering. The study's outcomes offer a foundation for numerical models to predict fire resistance, potentially influencing future building codes and standards.

2.4 Summary

The post-fire behavior of reinforced concrete, including residual flexural capacity, mechanical behavior prediction, and the effects of high temperatures on concrete characteristics, are summarized in this section from a variety of research.

CHAPTER 3
MODELING & ANALYSIS

3.1 General

This chapter provides a detailed overview of sample beams, including their material properties and specific specifications. These beams were meticulously designed using AutoCAD 2022 and analyzed using Finite Element Analysis (FEA) software, ABAQUS 2017. The chapter presents a step-by-step guide on conducting FEA and details the model's characteristics.

The researcher conducted experimental tests on two beams, rigorously verifying the results using the ABAQUS software. The beams measured 3952 mm × 406 mm × 254 mm (Kodur M. B., 2009). Our focus primarily lies on analyzing one beam, considering important factors like material properties, compression angle, viscosity, density, concrete damage plasticity, and the impact of mesh size. These analyses were carried out using the advanced finite element program ABAQUS.

3.2 Specifications of the specimen

The exact dimensions of 3952 mm × 406 mm × 254 mm, which ensures stability and allows a controlled comparison throughout the numerical analysis (Kodur M. B., 2009). The consistent dimensions of these beams allow for a systematic comparison, enabling a thorough analysis of their reactions under various conditions. The uniformity in beam size enhances the reliability of the numerical analysis, providing an adequate basis for evaluating and contrasting the efficiency of different beam categories. The left side of each beam is supported by a spring with a length of 147 mm, while the right

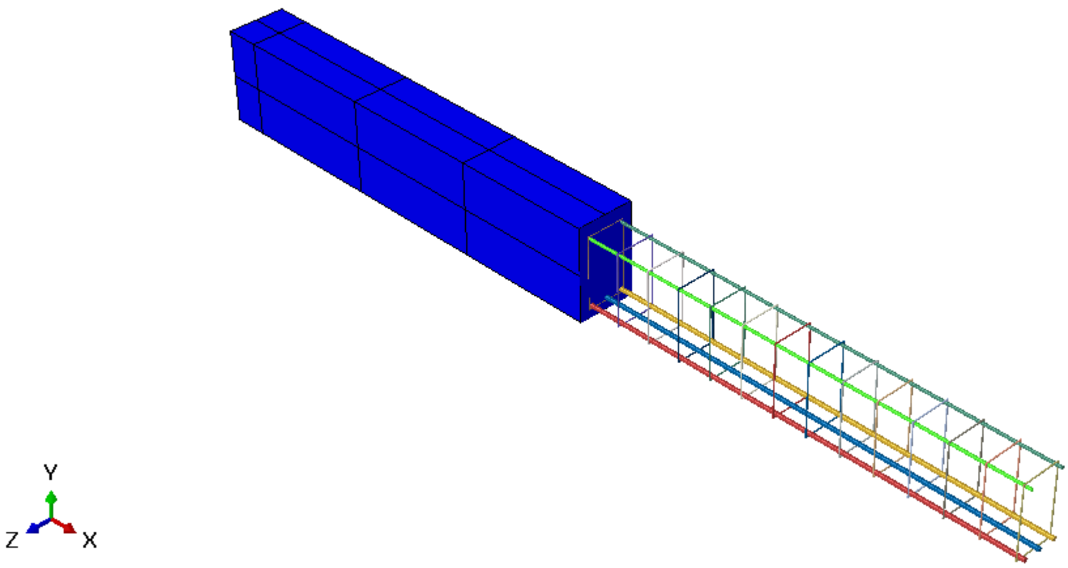


Figure 3.1: 3D View of Concrete beam.

side is supported by a roller with a height of 147 mm. These supports play a role in determining the overall structural behavior. Figure 3.1 displays a comprehensive 3D representation of a concrete beam.

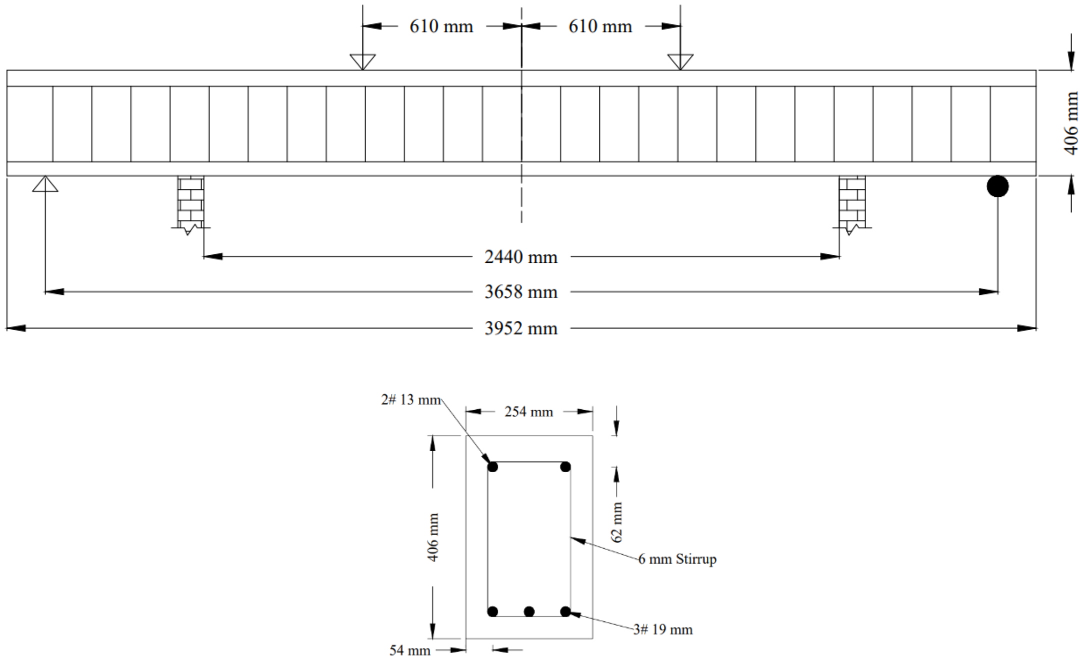


Figure 3.2: 2D View of Specification of the Specimen (B1) (Kodur M. B., 2009).

As shown Figure 3.2 the beam has two loading points that are appropriately linked to the top surface of the beam, allowing the beams to respond differently to varied loads. The beam is reinforced with two layers of rebars: 13mm diameter reinforcements on the top and 19mm diameter reinforcements on the bottom. Stirrups: Make sure the beam has lateral reinforcement using stirrups with a diameter of 6 millimeters. The nominal thickness of the transparent cover on both sides is thirty millimeters. A clear cover of 34mm is maintained on the top and two sides, while a clear cover of 54mm is ensured on the bottom of the beam. During testing, a fire is applied to the middle portion of the beam, specifically affecting a length of 2440 millimeters from below and on both sides. However, no fire is applied to the top surface of the beam.

3.3 Reinforcement Concrete Beam

Reinforced concrete beams are vital elements in building structures, designed to bear loads that act perpendicular to their length. These loads create different types of forces within the beams, including bending, shear, and torsion. Concrete itself is strong under compression but weak under tension, so steel reinforcement is added to withstand tensile stresses.

These beams carry the weight of various structural elements like slabs, other beams, walls, and columns, and transfer this load to the supporting columns of the structure. They come in different shapes such as rectangular, square, T-shaped, or L-shaped, depending on the specific requirements of the building design. Engineers may choose to reinforce beams with a single layer or double layer of steel, depending on the anticipated loads and structural requirements.

To illustrate, imagine a bridge where the beams support the weight of the roadway and transfer it to the supporting columns or piers beneath. In a building, beams support the weight of floors, walls, and ceilings, ensuring structural stability and safety. A three-dimensional representation of a reinforced concrete beam is depicted in Figure 3.1, providing a visual aid to understand its structure and reinforcement.

3.4 Material Property

This study aims to experimentally verify the performance of reinforced concrete (RC) beams that respond to fire using Finite Element Analysis (FEA) software. The primary goal is to develop accurate methods for assessing the structural integrity of RC beams, ensuring they remain safe and effective under fire conditions. To achieve this, the beam was tested under various conditions, as detailed in Table 3.1 (Ankit Agrawal, 2016)

Table 3.1: Material Properties

Beam	Concrete Strength (MPa)	Steel Strength (MPa)	Modulus of Elasticity of Concrete (GPa)	Modulus of Elasticity of Steel (GPa)
B1	58	420	27	200

By conducting experimental tests and utilizing FEA software, researchers aim to understand how RC beams behave when exposed to fire. This information is crucial for improving safety standards and design practices for RC structures, ensuring their reliability and effectiveness in real-world situations.

3.5 Concrete Property

The understanding of temperature and loading conditions is fundamental for designing and analyzing concrete structures. Thermal conductivity, representing concrete's heat conduction capability, is a critical parameter influencing its thermal behavior. Typically, thermal conductivity is temperature-dependent, often increasing with rising temperatures due to alterations in material properties and induced microstructural changes. Specific heat capacity, another crucial aspect, quantifies the heat required to raise the temperature of a unit mass of concrete by one degree Celsius. Recognizing the temperature dependency of specific heat is essential, given the significant variations in concrete's thermal behavior across different temperature ranges. Moreover, the coefficient of thermal expansion plays a crucial role in predicting thermal stresses and deformations in concrete structures under fire conditions. Concrete expansion or contraction with fluctuating temperatures necessitates precise consideration of this parameter in structural analyses to ensure resilience and safety. Additionally, concrete strength diminishes at elevated temperatures due to thermal expansion, microcracking, and alterations in material properties. Incorporating temperature-dependent strength reduction models is essential for realistic simulations of concrete behavior during fire scenarios, facilitating the design of structures capable of withstanding extreme conditions. Furthermore, emissivity, representing a material's efficiency in emitting thermal radiation, varies with temperature, affecting concrete's heat transfer characteristics and its overall response to fire exposure. Heat capacity, measuring the heat energy required to raise concrete's temperature by one degree Celsius for a given mass, also exhibits temperature dependency, contributing to accurate modeling of concrete structures' thermal response during fire events. Lastly, concrete density changes with temperature due to thermal expansion and contraction. Accounting for temperature-dependent density changes enables more precise predictions of concrete behavior in fire conditions, particularly in structural analyses where mass distribution significantly influences performance. Integrating these temperature-related properties in engineering analyses ensures more realistic assessments and designs, promoting the durability and safety of concrete structures across various environmental conditions. Shown Figure 3.3 concrete material properties graph.

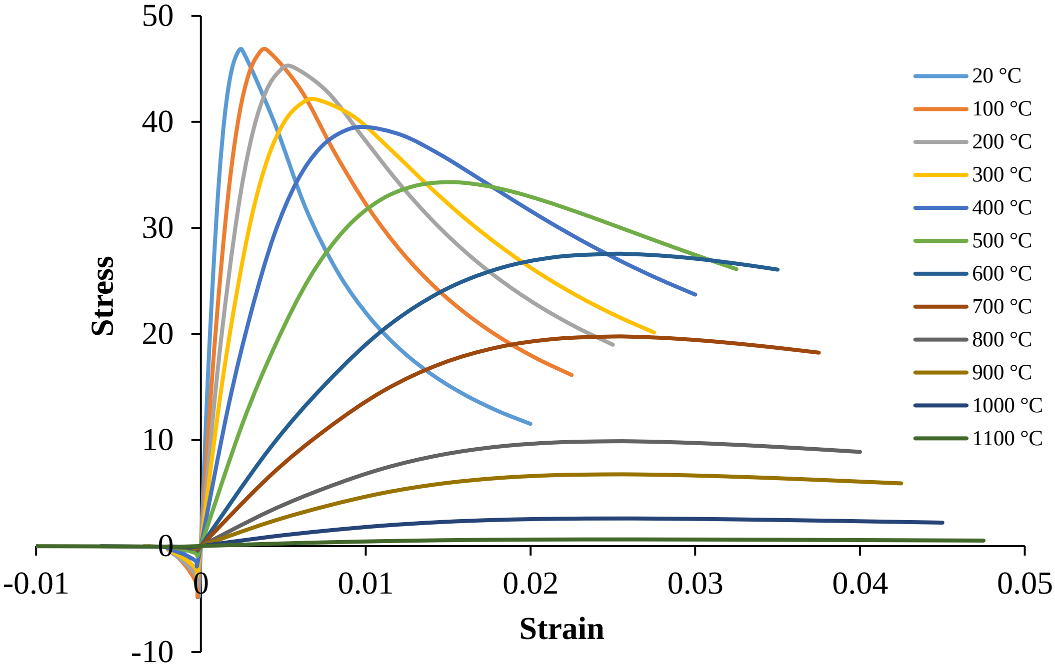


Figure 3.3: Stress-strain curve of different temperatures of concrete for RC beam (CEN, 2004).

3.5.1 Conductivity

Figure 3.4 the thermal conductivity of concrete in reinforced concrete beams was analyzed using Abaqus finite element analysis (FEA) software. By leveraging FEA, we were able to simulate and predict the heat transfer behavior within the concrete material under varying conditions. Understanding the thermal conductivity of concrete is crucial for assessing its response to temperature differentials and thermal gradients, particularly in structures subjected to environmental variations. Through numerical modeling, factors affecting thermal conductivity, such as material composition, moisture content, and aggregate properties, were considered. This approach enabled us to evaluate the influence of these factors on the thermal performance of reinforced concrete beams, providing insights into potential thermal stresses and implications for structural integrity. Additionally, the use of FEA facilitated the exploration of design strategies to mitigate the effects of thermal conductivity, enhancing energy efficiency and durability in concrete structures. By employing Abaqus software, we were able to conduct detailed analyses and simulations, contributing to a deeper understanding of thermal behavior in reinforced concrete beams and informing more robust design practices.

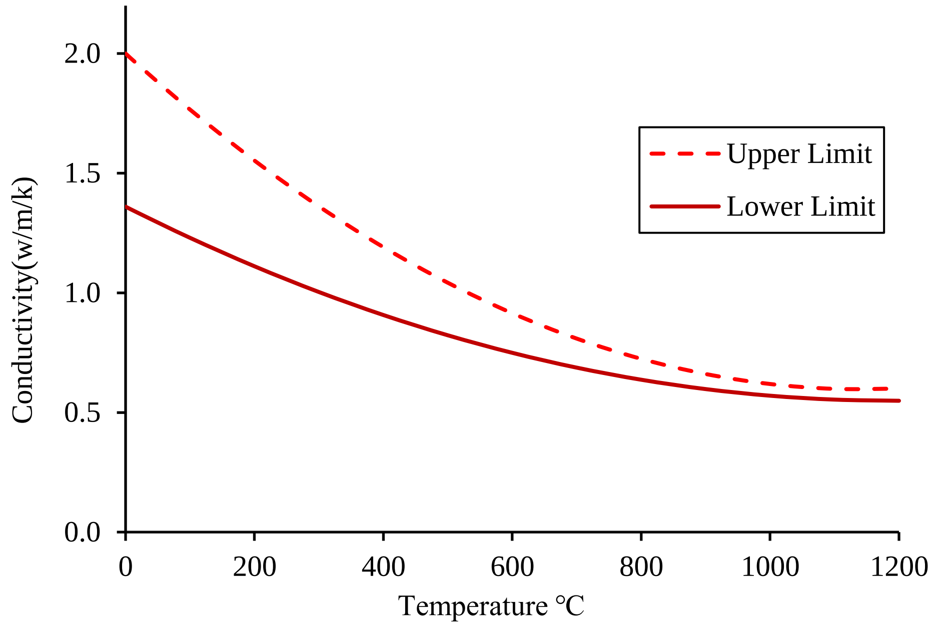


Figure 3.4: Temperature-Dependent Conductivity of Concrete (CEN, 2004).

3.5.2 Elasticity of Concrete

The elasticity of concrete concerning temperature variations is paramount for ensuring the integrity and safety of infrastructure subjected to diverse environmental conditions. Through advanced computational analysis using Finite Element Analysis (FEA) software like Abaqus, researchers and engineers delve into the intricate behavior of concrete under thermal influences. Temperature-induced effects on concrete elasticity encompass a spectrum of phenomena, from thermal expansion and contraction to the evolution of internal stresses. As concrete heats up or cools down, its thermal expansion and contraction lead to dimensional changes that can induce significant stress within the material. These internal stresses, in turn, influence the concrete's elastic behavior, altering its response to applied loads. Moreover, non-uniform temperature distributions across concrete structures create thermal gradients, exacerbating stress differentials and potentially triggering deformations or cracking. FEA simulations allow for the precise modeling of these thermal gradients and their impact on concrete elasticity, providing valuable insights for optimizing structural designs and mitigating potential risks. Furthermore, the analysis of concrete's elastic modulus variation with temperature is crucial. Elevated temperatures can lead to a reduction in the elastic modulus, making the concrete less resistant to deformation. This knowledge aids in developing strategies to enhance the thermal stability of concrete structures, whether through material composition adjustments, thermal insulation measures, or innovative design solutions.

Ultimately, the marriage of computational analysis tools like Abaqus with theoretical insights into the elasticity of concrete under temperature fluctuations drives advancements in structural engineering practices, ensuring the resilience and longevity of critical infrastructure in a dynamic thermal environment.

3.5.3 Specific Heat

The specific heat of concrete, a fundamental thermal property, holds significant importance in structural engineering and finite element analysis (FEA) for accurately modeling the behavior of concrete structures under varying temperature conditions. Concrete, being a prevalent construction material, possesses distinct thermal properties, among which specific heat stands out as a key parameter. Specific heat, denoted as C, quantifies the amount of heat energy required to raise the temperature of a unit mass of concrete by one degree Celsius or Kelvin. In the context of finite element analysis (FEA) utilizing Abaqus software, precise characterization of concrete's specific heat is essential for simulating thermal phenomena with fidelity. Through numerical simulations, Abaqus enables engineers and researchers to assess the thermal response of concrete structures under diverse environmental conditions and loading scenarios, providing insights into temperature distribution, thermal stresses, and potential durability issues. Accurate representation of specific heat within Abaqus models facilitates the realistic emulation of heat transfer processes within concrete elements, contributing to enhanced predictive capabilities in structural analysis and design. Calibration and validation of concrete material properties, including specific heat, against experimental data further refine the accuracy and reliability of thermal simulations conducted using Abaqus, bolstering its utility in the realm of structural engineering.

Figure 3.5 depicts the variation of specific heat of concrete as temperature increases. It shows three different curves for concrete with 0%, 1.5%, and 3% moisture content (MC), indicating that specific heat changes with both temperature and moisture content. The graph uses temperature in Celsius and specific heat in KJ/kg/k.

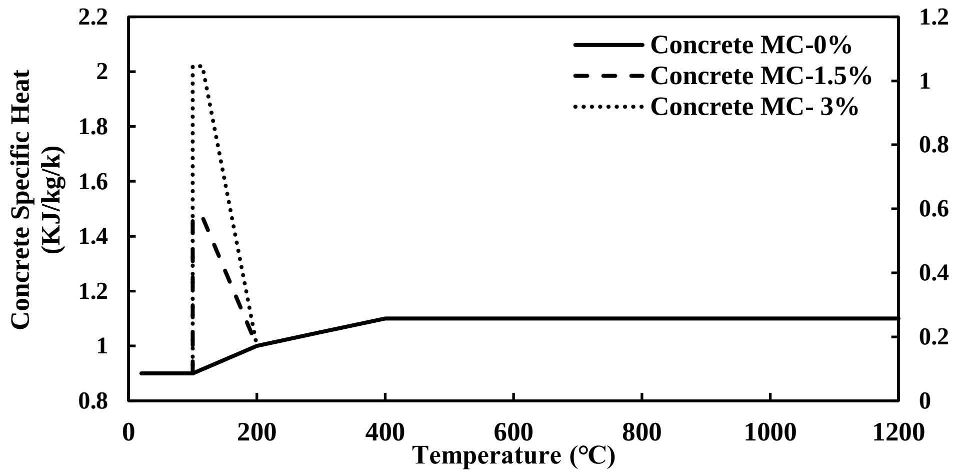


Figure 3.5: Specific Heat Variation of Concrete with Temperature (CEN, 2004).

3.5.4 Concrete Damage Plasticity

Concrete Damage Plasticity is a technique used in ABAQUS software to accurately simulate the nonlinear behavior of concrete structures. This method employs constitutive modeling techniques, incorporating damage variables to track material deterioration. This allows for a comprehensive representation of plastic deformation and damage accumulation.

The dilation angle measures the change in volume of the material under stress, while eccentricity quantifies the displacement between applied loads and the central axis of structural components. ABAQUS also considers viscosity as a material property Table 3.*2*, allowing for the representation of time-dependent phenomena and dynamic responses in structural analyses.

Table 3.2: Concrete damage plasticity input data

Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
31	0.1	1.16	0.67	0.001 to 0.000001

In concrete materials, the optimum dilation angle parameter typically ranges from 25° to 31°, with an optimal Kc value of 0.667 (M.A. Najafgholipour, 2017). Adjusting viscosity intentionally enables researchers to observe its impact on the beams' behavior during analysis, providing valuable insights into its role in structural performance. This information is further elaborated on in the subsequent chapter of this study.

3.6 Steel Property

The behavior of steel is intricately tied to temperature variations, which significantly influence its mechanical and thermal properties. Notably, the strength of steel diminishes as the temperature rises due to thermal softening mechanisms, leading to decreases in both yield strength and ultimate tensile strength. This decline arises from heightened dislocation mobility within the crystal lattice of the steel. Conversely, at lower temperatures, steel exhibits reduced ductility, becoming more prone to brittle fracture under load. However, at extremely high temperatures, ductility can also decrease as a result of thermal deformation mechanisms like creep. Young's modulus, representing steel's stiffness, typically remains stable across temperature ranges, exhibiting only minor fluctuations that are often negligible compared to alterations in strength and ductility.

Thermal expansion is a crucial consideration for steel applications, as it expands when heated and contracts when cooled. This phenomenon's rate varies with temperature, impacting dimensional stability, especially over wide temperature ranges. While steel boasts good thermal conductivity, its conductivity may marginally decrease with rising temperature, albeit insignificantly in most cases, impacting the overall thermal performance of steel structures to a minimal extent. Specific heat capacity, denoting the amount of heat required to raise steel's temperature by one degree Celsius, tends to remain relatively constant over a broad temperature range. Nevertheless, slight variations in specific heat capacity can occur due to changes in steel composition and microstructure.

The magnetic properties of steel are temperature-sensitive, exemplified by the Curie temperature. This critical temperature marks the point at which a ferromagnetic material like steel loses its magnetic properties, transitioning to a paramagnetic state with weak magnetic behavior. Understanding these temperature-dependent properties is fundamental in engineering design and analysis, enabling the effective utilization of steel across diverse applications while considering varying thermal conditions. Shown Figure 3.6 steel material properties graph.

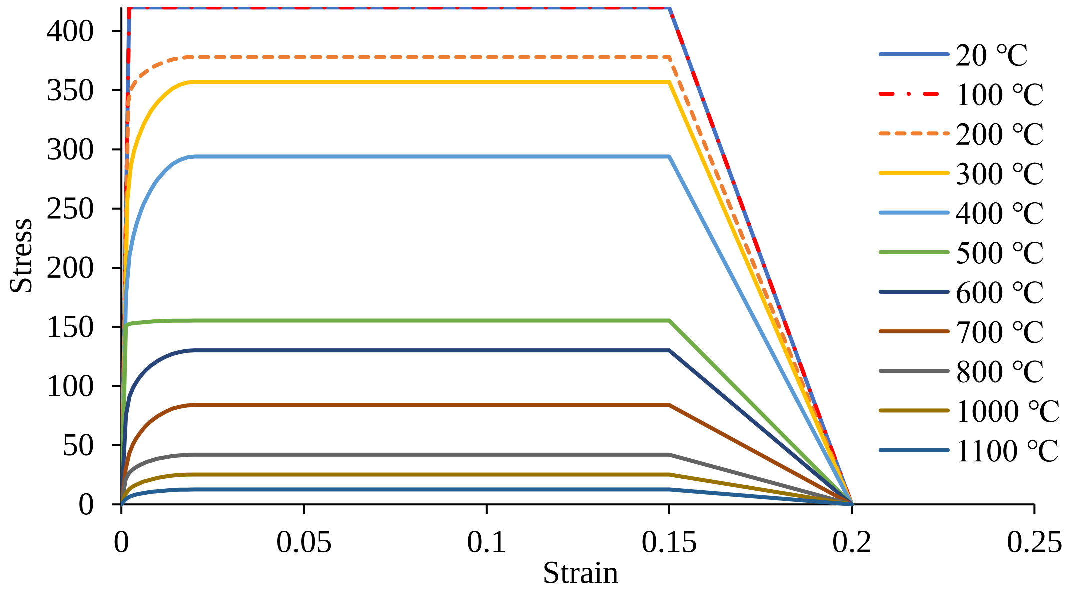


Figure 3.6: Stress-Strain curve of different temperatures of steel for RC beam (CEN, 2004).

3.6.1 Conductivity

In the investigation of reinforced concrete beams, understanding the thermal conductivity of steel, a primary reinforcement material, is fundamental for predicting thermal behaviors and ensuring structural integrity. Thermal conductivity, denoted by k, quantifies the ability of steel to conduct heat, which is crucial for assessing temperature distributions, thermal gradients, and thermal stresses within reinforced concrete beams subjected to varying environmental conditions. Through the utilization of Abaqus finite element analysis (FEA) software, researchers and engineers can simulate the complex thermal interactions between steel reinforcement and concrete matrix with precision and reliability. By accurately modeling the composition, geometry, and boundary conditions of the reinforced concrete beam, Abaqus enables the estimation of thermal responses, facilitating insights into the effects of material properties, reinforcement layouts, and external factors on thermal performance. This analytical approach empowers designers to optimize the design of reinforced concrete beams, enhancing durability, mitigating thermal stresses, and improving energy efficiency in structures. Moreover, the ability to validate FEA results against experimental data enhances the credibility and applicability of the findings, further solidifying the role of Abaqus as an invaluable tool in advancing the understanding and design of steel-reinforced concrete structures. The conductivity material graph is shown Figure 3.7 for steel.

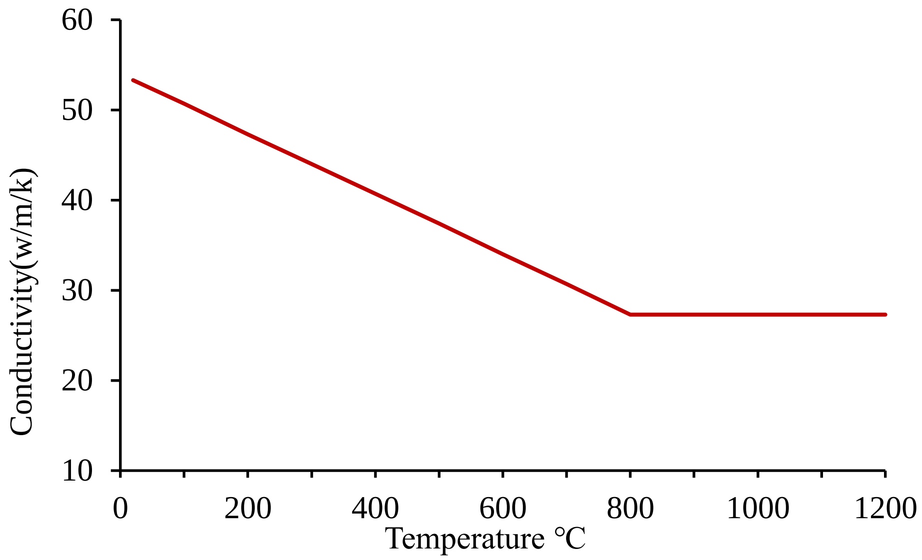


Figure 3.7: Temperature-Dependent Conductivity of Steel (CEN, 2004).

3.6.2 Elasticity

The study of reinforcement elasticity within reinforced concrete beams is fundamental in structural engineering and crucial for ensuring the stability and performance of concrete structures. Utilizing sophisticated computational tools such as Abaqus finite element analysis (FEA) software offers a robust approach to examining the behavior of reinforcement under various loading conditions. Through advanced numerical simulations, engineers can model the interaction between the reinforcement and surrounding concrete matrix, capturing the complex mechanical responses within reinforced concrete beams with high accuracy. Abaqus enables the incorporation of detailed material properties, geometric configurations, and boundary conditions into the analysis, facilitating the investigation of stress distribution, strain patterns, and load-carrying capacities of the reinforcement. By simulating the behavior of reinforced concrete beams subjected to different loading scenarios, including bending, shear, and torsion, Abaqus provides valuable insights into the elasticity of reinforcement and its contribution to the overall structural behavior. These simulations aid in optimizing design parameters, such as reinforcement arrangement and quantity, to enhance the strength, ductility, and durability of reinforced concrete structures for practical engineering applications.

3.6.3 Specific Heat

The specific heat of reinforcement materials holds crucial significance in the thermal analysis of reinforced concrete beams, a cornerstone in structural engineering and finite element analysis (FEA) studies. Reinforced concrete beams, ubiquitous in construction, comprise a composite material system integrating concrete and steel reinforcement bars (rebars). While concrete's thermal properties are extensively studied and characterized, the specific heat of reinforcement materials, particularly steel rebars, is equally vital in accurately modeling the thermal behavior of reinforced concrete elements. Specific heat, denoted by 'C,' signifies the energy required to raise the temperature of a unit mass of a material by one degree Celsius or Kelvin. In computational analyses conducted using Abaqus FEA software, incorporating the specific heat of reinforcement materials enables engineers to simulate heat transfer phenomena within reinforced concrete beams under varying thermal loading conditions. By accurately accounting for the thermal properties of both concrete and steel rebars, researchers can predict temperature distributions, thermal gradients, and associated stresses within reinforced concrete members, facilitating the assessment of structural performance and durability. Through meticulous calibration and validation against experimental data, Abaqus offers a robust platform for integrating complex material models and boundary conditions, allowing for precise simulations of thermal responses in reinforced concrete beams. Thus, a comprehensive understanding of the specific heat of reinforcement materials, coupled with advanced computational tools like Abaqus, empowers engineers to optimize the design and thermal performance of reinforced concrete structures, ensuring resilience and longevity in construction practices.

Figure 3.8 depicts the Specific Heat Variation of Steel as a function of temperature. It shows that specific heat, measured in J/kg/K, increases with temperature, ranging from 0°C to 1200°C. The graph indicates a non-linear relationship, with specific heat values rising as temperature increases.

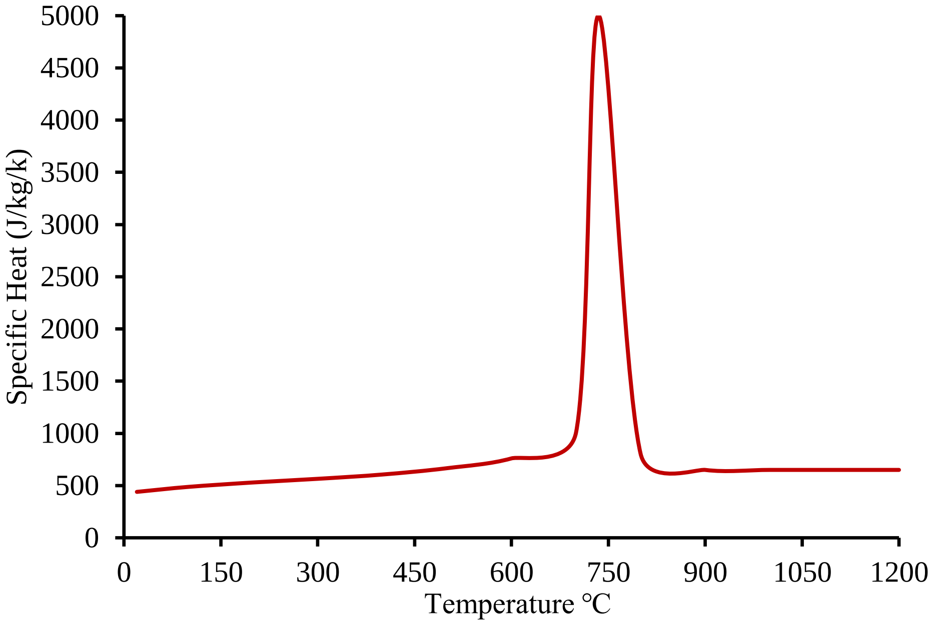


Figure 3.8: Specific Heat Variation of Steel with Temperature (CEN, 2004).

3.6.4 Plasticity

In this study of reinforced concrete beam analysis, particularly concerning heat transfer considerations, understanding the plasticity of reinforcement materials is paramount for accurate modeling and prediction of structural behavior. Utilizing finite element analysis (FEA) software such as Abaqus allows for sophisticated simulations that delve into the intricate interplay between heat distribution and mechanical response within concrete beams.

The plasticity of reinforcement comes into focus as the beam undergoes thermal loading, a scenario where the beam is subjected to elevated temperatures. In such conditions, the material properties of both the concrete and the reinforcement are significantly altered, leading to thermal expansion, softening, and potential degradation. The reinforcement, typically steel bars, exhibits plastic behavior when subjected to these elevated temperatures, experiencing nonlinear deformation and yielding phenomena. Understanding the onset and progression of plasticity within the reinforcement is essential for accurately predicting the structural response under thermal loads.

Abaqus offers a robust platform for incorporating the plasticity of reinforcement into heat transfer analyses of reinforced concrete beams. By employing advanced material models that capture the nonlinear behavior of the reinforcement under elevated temperatures, engineers can simulate the redistribution of stresses and strains within the beam as it responds to thermal gradients. This comprehensive analysis allows for the assessment of critical factors such as load-carrying capacity, deflection, and failure modes under different thermal scenarios.

3.7 Element Type

The Finite Element Model (FEM) utilized for concrete structures employs C3D8T elements for geometrically linear order and family-coupled temperature-displacement analyses, featuring 8 nodes and thermally coupled brick properties, while steel components are represented using T3D2T elements with 3 nodes and thermally coupled truss characteristics. These elements, depicted in Figure 3.9 of the model, accurately capture the complex behavior of concrete and steel under different loading and thermal conditions. Incorporating interaction properties with the film condition approach, the model accounts for heat transfer between materials, crucial for simulating fire and non-fire scenarios. The film coefficients, set at 0.025 for fire and 0.009 for non-fire conditions, regulate thermal exchange between materials, ensuring realistic simulation outcomes.

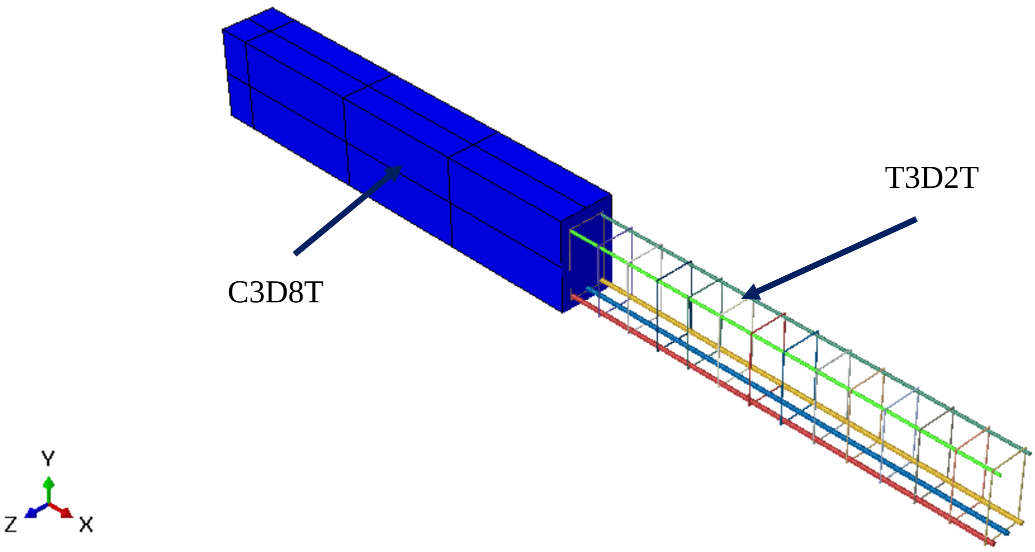


Figure 3.9: Types of Elements.

3.8 Interaction Across Elements

In the structural analysis conducted using ABAQUS software, a comprehensive set of interaction tools was devised to simulate the behavior of a composite beam under different environmental conditions. Specifically, two key interactions, denoted as "U," were meticulously positioned within the model: one situated atop the middle beam's surface and the other positioned beneath the reinforcement layer along the beam's midpoint.

To effectively represent the varying thermal conditions, the model incorporated two distinct surface regions: "fire" and "non-fire." The "fire" region encompassed a surface extending 2240 mm in length along the lower periphery and lateral sides of the beam, intended to emulate the effects of thermal exposure. Conversely, the "non-fire" surface was designated to represent the segment of the beam shielded from direct heat exposure.

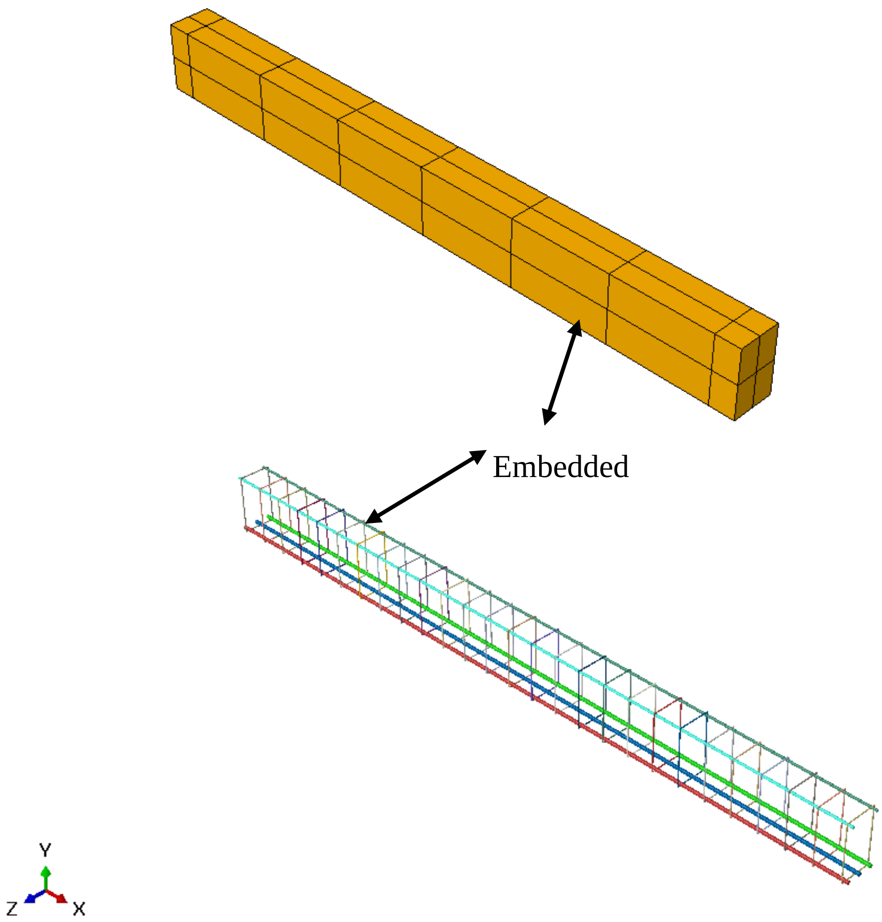


Figure 3.10: Interaction of RC Beams in FEA.

With meticulous attention to detail, three distinct interaction models were developed to accurately capture the nuanced behaviors within the system: two interactions were meticulously tailored to mimic the effects of fire, while a third interaction encapsulated the non-fire scenario. Each interaction model was precisely calibrated to correspond to its respective environmental conditions, ensuring a comprehensive representation of the system's response under diverse thermal circumstances.

Central to the analysis was the implementation of the film condition type, featuring two distinct interaction properties: "fire" and "non-fire." These properties were meticulously configured to encapsulate the thermal responses exhibited by the materials within the model, allowing for a nuanced depiction of the interfacial behaviors under varying temperature regimes.

Furthermore, to accurately capture the intricate interplay between the components, the reinforcement, and concrete elements were strategically embedded within constraints and securely Tie to each loading and support point. This meticulous approach ensured that the structural response of the composite beam was faithfully simulated, providing invaluable insights into its performance under differing environmental conditions.

Reinforcement elements and concrete materials were embedded within the structural model, as depicted in Figure 3.10 & Figure 3.11. This integration facilitates a comprehensive assessment of the structural response to applied loads and environmental conditions.

Reinforcement elements, typically comprising steel bars or mesh, are strategically positioned within the concrete matrix to enhance structural strength and durability. These elements are accurately represented in the FEA model to capture their contribution to the overall structural behavior under various loading scenarios.

The concrete material properties, including compressive strength, elastic modulus, and thermal conductivity, among others, are defined within the Abaqus model to accurately simulate the behavior of the concrete components. This allows for the evaluation of concrete deformation, cracking, and failure mechanisms under different loading conditions, including fire exposure.

The embedded reinforcement and concrete components are meticulously modeled in Abaqus to ensure geometric accuracy and material representation, enabling a realistic simulation of structural response. This level of detail enhances the predictive capability of the analysis and provides valuable insights into the performance of the reinforced concrete structure.

By incorporating reinforcement and concrete elements within the FEA model, engineers can assess critical aspects such as load-carrying capacity, deflection behavior, and structural integrity, aiding in the design optimization and validation process. This integrated approach facilitates informed decision-making and enhances the safety and reliability of the structural design.

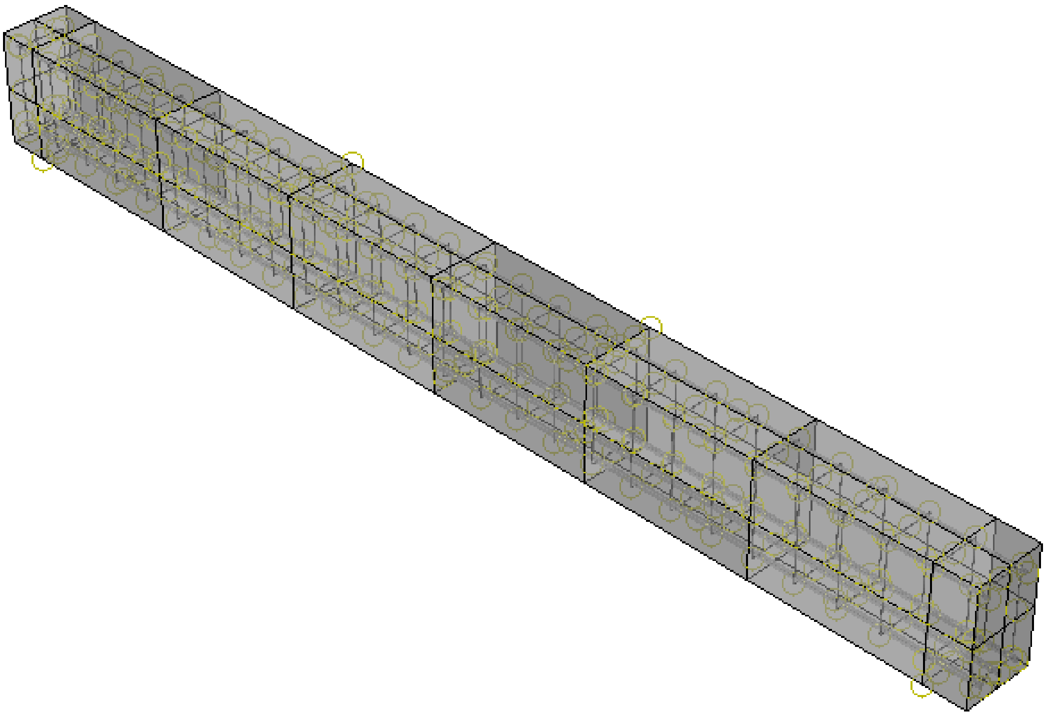


Figure 3.11: Embedded condition of RC Beams in FEA.

3.9 Meshing

Meshing is a critical step in finite element analysis (FEA) used in ABAQUS software. It involves breaking down complex geometries into smaller, simpler elements to create a numerical representation of the structure's behavior under various conditions. This conversion from a physical model to a mathematical representation ensures the accuracy and effectiveness of simulations.

Accurate and interconnected models enable the software to accurately simulate the structural response, providing valuable insights into how the system behaves under different loads and boundary conditions. Meshing is a vital procedure in analysis, ensuring the precision and reliability of numerical simulation results.

In our study, we created six different mesh versions for each beam. The mesh sizes varied from 15 to 50 millimeters, with increments of 5 millimeters. Figure 3.12 shown the mesh of RC beam.

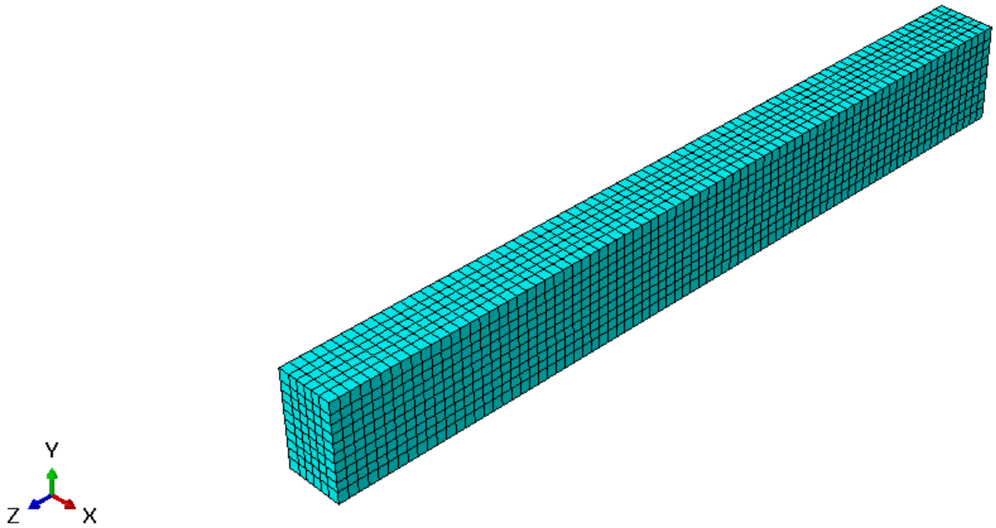


Figure 3.12:Analysis of Mesh Size for 3D RC Beam.

3.10 Boundary Conditions

In ABAQUS, defining boundary conditions involves specifying constraints like supports, while defining loads entails applying external forces or conditions that act on the structure. ABAQUS offers an intuitive interface for accurately simulating real-world scenarios, allowing precise specifications of constraints, displacements, and rotations.

Accurate simulation results in ABAQUS depend on well-defined boundary conditions and loading, which are crucial for capturing realistic structural responses and gaining valuable insights into system behavior. In our simulation, we replicated the actual experimental conditions by using four nodes to support the beams.

Constraints, referred to as "Tie" in ABAQUS, were applied to establish a rigid connection between the support and loading nodes, ensuring minimal movement between the beam. The loading was directly applied to the specified location on the beam.

Rigid loading points were utilized to impose displacement in the RC beam. The beam was supported on the left side by a 147 mm long spring and on the right side by a 147 mm long roller, contributing to the determination of the overall structural behavior. Figure 3.13 shown the loading points and supports.

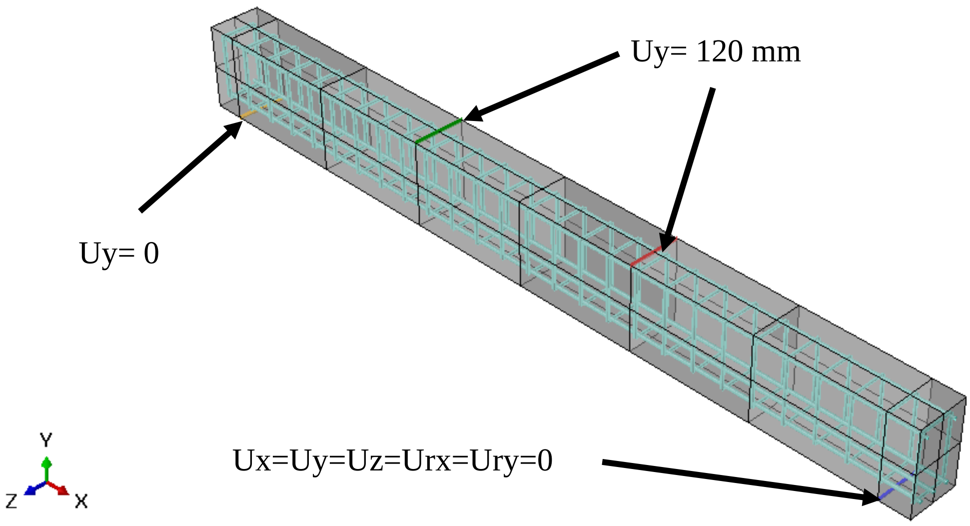


Figure 3.13: Loading & Boundary Condition.

3.11 Heat Transfer

In the Abaqus finite element analysis (FEA) simulation, a comprehensive approach was employed to assess structural response under varying conditions. Specifically, coupled temperature displacement analysis was conducted for both fire and static loading scenarios, alongside a general analysis for load conditions. This methodical procedure was executed within the step manager framework, ensuring meticulous consideration of thermal and mechanical influences on structural behavior.

The analysis spanned 60 minutes, allowing for a thorough examination of the structural response over time under the prescribed loading and temperature conditions. This extended timeframe facilitates the observation of transient effects, including thermal expansion, material degradation, and structural deformation, critical for understanding the evolution of the structural response.

Figure 3.14 visually delineates the area exposed to fire within the structural model, providing a spatial reference for the regions subjected to elevated temperatures during the analysis. This visual representation aids in the interpretation of results and facilitates targeted assessment of fire-induced effects on structural performance.

By leveraging Abaqus software for coupled temperature displacement analysis and incorporating both fire and static loading conditions within the step manager procedure, engineers can comprehensively evaluate structural responses to realistic operating scenarios. This integrated approach enables informed decision-making regarding design modifications or reinforcements necessary to enhance structural fire resistance and overall performance.

The utilization of Abaqus FEA software for coupled temperature displacement analysis, coupled with a comprehensive step manager procedure and an extended analysis duration, ensures a robust assessment of structural behavior under fire and static loading conditions, contributing to the development of safer and more resilient structures

a)

b)

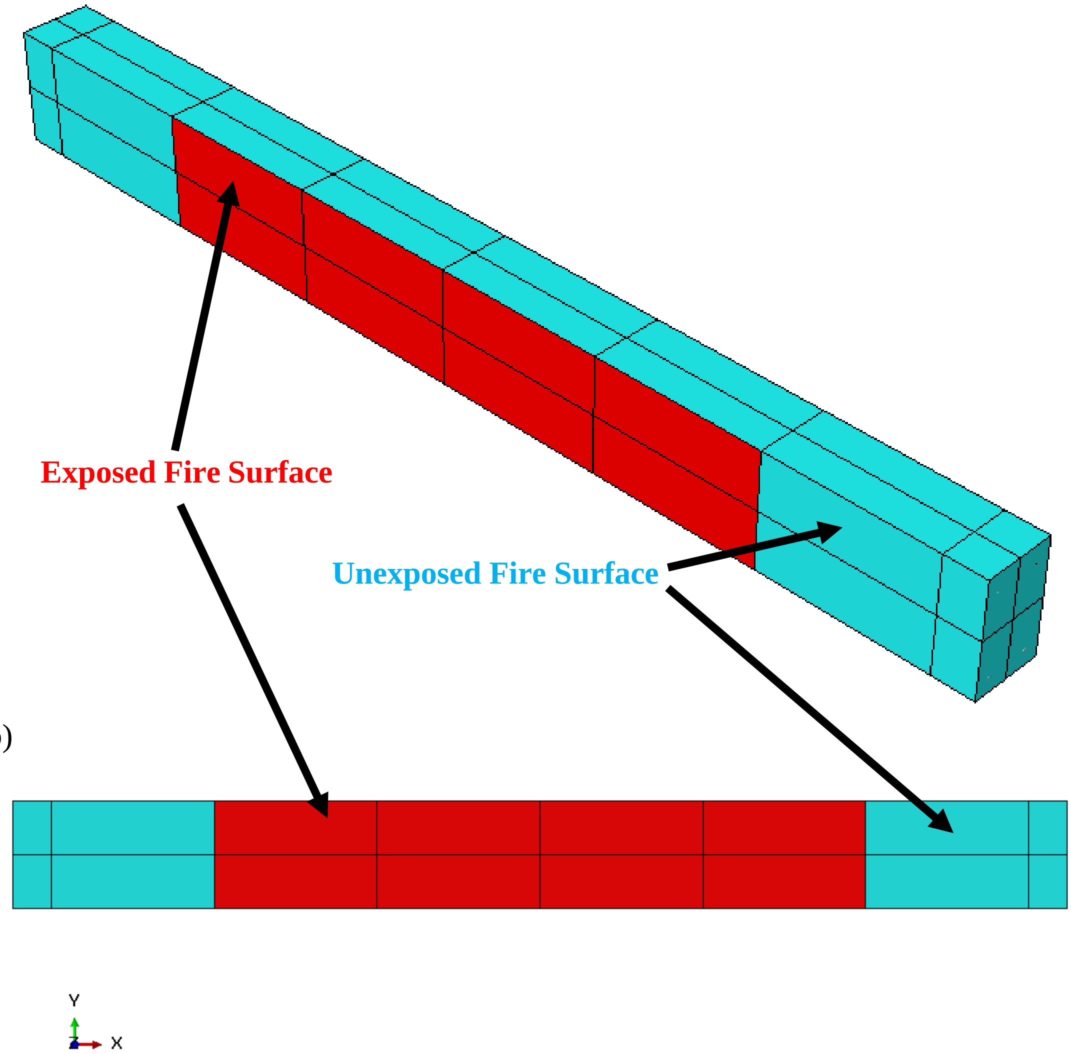


Figure 3.14: Fire Area of RC Beam: a) 3D View, And b) Bottom View.

3.12 Summary

The chapter details the creation and analysis of reinforced concrete beam models using ABAQUS software, focusing on material properties, meshing, and boundary conditions to simulate fire effects.

CHAPTER 4
RESULT AND DISCUSSION

4.1 General

In our study, we conducted a comprehensive analysis utilizing ABAQUS software to investigate the fire resistance capability of reinforced concrete beams under varying mesh and viscosity characteristics. The primary objective was to assess the structural behavior and performance of these beams under different conditions. To achieve this, we meticulously examined the material characteristics incorporated into our modeling studies. This involved a thorough exploration of parameters such as dilation angle, viscosity variations, and mesh size influence, which are crucial factors affecting the ultimate failure loads in both experimental and ABAQUS analyses.

The findings encapsulate a nuanced understanding of the structural behavior across a spectrum of scenarios, shedding light on the efficacy of the applied parameters and their interplay with the beam's performance. By meticulously dissecting the effects of each variable, invaluable insights are provided into the beam's response under different settings, furnishing practitioners and researchers alike with a robust framework for evaluating structural performance. The chapter serves as a pivotal platform for scrutinizing the intricacies of the research, offering a meticulous exploration of each variable's complexities and their ramifications on the overarching structural response.

We have garnered a wealth of data elucidating the dynamic interplay between material characteristics and structural behavior through rigorous experimentation and meticulous computational analyses conducted via ABAQUS software. Our discourse transcends mere observation, delving into the underlying mechanisms governing the beam's response and providing a holistic understanding of its performance under diverse conditions. This chapter stands as a testament to our commitment to advancing knowledge in structural engineering, offering a comprehensive synthesis of our findings and paving the way for further inquiry into the intricate dynamics of reinforced concrete structures.

4.2 Validation of Finite Element Models

Heat transfer in reinforced concrete beams is critical to structural analysis, particularly in scenarios involving fire exposure or elevated temperatures. The accurate prediction of heat transfer phenomena is essential for assessing the structural response and ensuring the safety and reliability of reinforced concrete structures. In this study, conducted using ABAQUS software, the heat transfer process in reinforced concrete beams is comprehensively investigated through finite element analysis (FEA) to validate the precision and dependability of the computational model.

The validation process involves systematically examining various parameters that influence heat transfer behavior, including dilation angles, viscosity, steel grade, meshing techniques, and the modulus of elasticity of steel. Sensitivity analysis is employed to assess the impact of parameter adjustments on the predictive capabilities of the FEA model. By systematically adjusting these parameters and comparing the FEA predictions with empirical data, the accuracy and responsiveness of the model under different circumstances are evaluated.

Through this rigorous validation technique, a thorough understanding of the model's behavior across diverse conditions is attained, confirming its reliability in precisely forecasting the structural reaction of reinforced concrete beams. The investigation not only enhances confidence in the computational model but also provides valuable insights into the factors affecting heat transfer in reinforced concrete structures. Ultimately, this research contributes to the advancement of structural engineering practices by providing validated computational tools for designing and analyzing reinforced concrete beams under varying thermal conditions.

4.3 Temperature Validation

Numerous trials were conducted to refine the Abaqus model parameters and ensure accurate predictions of the temperature distribution within the reinforced concrete beam under fire conditions. These trials encompassed variations in material properties, interaction settings, and mesh sizes to evaluate their impact on the simulation results. Initially, the material properties of concrete were explored across a spectrum, utilizing upper limit, lower limit, and average values. This allowed for a comprehensive understanding of how variations in thermal conductivity and specific heat influenced the simulated temperature distribution.

Additionally, different combinations of interaction settings were tested to accurately model the interaction with the fire surface. This included adjusting parameters such as emissivity, which ranged from 0.6 to 0.8, to reflect the surface's ability to emit thermal radiation effectively. Furthermore, the mesh sizes ranging from 15 mm to 50 mm were evaluated to determine their effect on the simulation accuracy. Through this analysis, it was possible to identify the optimal mesh size that balanced computational efficiency with solution accuracy.

After multiple iterations, it was observed that trials utilizing lower conductivity values, an emissivity of 0.8, a mesh size of 25 mm, and Furnace Temperature (SF) consistently yielded satisfactory results. In this analysis, conductivity incorporated lower limit conductivity values, an emissivity of 0.8, and a mesh size of 25 mm gave very good FEA results. The comparison between FEA results and experimental results for many conditions showed good accuracy for average conductivity values, an emissivity of 0.8, and a mesh size of 25 mm. These parameters were deemed optimal as they provided a good balance between computational efficiency and accuracy in predicting the temperature distribution within the reinforced concrete beam.

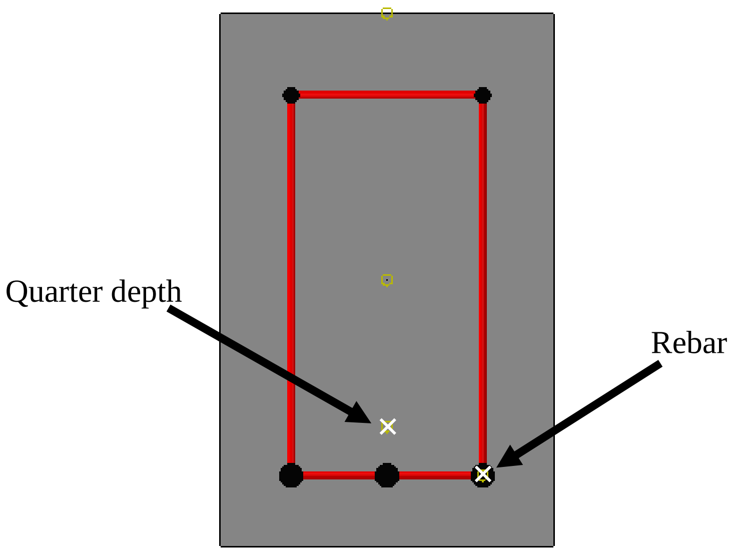


Figure 4.1: Thermocouple location of experimental beam.

Figure 4.1 shows the location of thermocouples in an experimental beam. It likely depicts a cross-sectional view of the beam, referred to as “Quarter depth,” which is a specific point or layer within the beam’s structure. The term “Rebar” suggests that the figure includes the representation of reinforcing bars, which are typically embedded in the concrete to enhance its strength. The thermocouples are probably positioned at strategic points to measure temperature variations within the beam, which could be crucial for assessing the material’s behavior under different conditions. This setup is essential for experimental analysis in structural engineering, particularly in the study of thermal effects on reinforced concrete structures.

The data presented in Figure 4.2 indicates a comparison of temperature measurements at different locations of a tested reinforced concrete beam over time. The Exp_Rebar and FEA_Rebar lines likely represent the experimental and finite element analysis (FEA) temperature readings at the rebar level within the concrete beam. Similarly, Exp_Quarter Depth and FEA_Quarter Depth probably denote the temperature readings at a quarter depth of the beam.

From the context provided, it seems that the temperatures were recorded over a period of 60 minutes and reached up to 1200°C. The comparison would involve analyzing how closely the FEA results (FEA_Rebar and FEA_Quarter Depth) match with the experimental results (Exp_Rebar and Exp_Quarter Depth). The results would reveal the accuracy of the FEA model in predicting the temperature distribution within the concrete beam under test conditions. Unfortunately, without specific numerical values or trends from the graph, I cannot provide a detailed analysis of the results. However, the graph suggests that there is a comparison of temperatures at the rebar level and at a quarter depth of the beam over time, which is crucial for assessing the thermal performance of reinforced concrete in fire conditions.

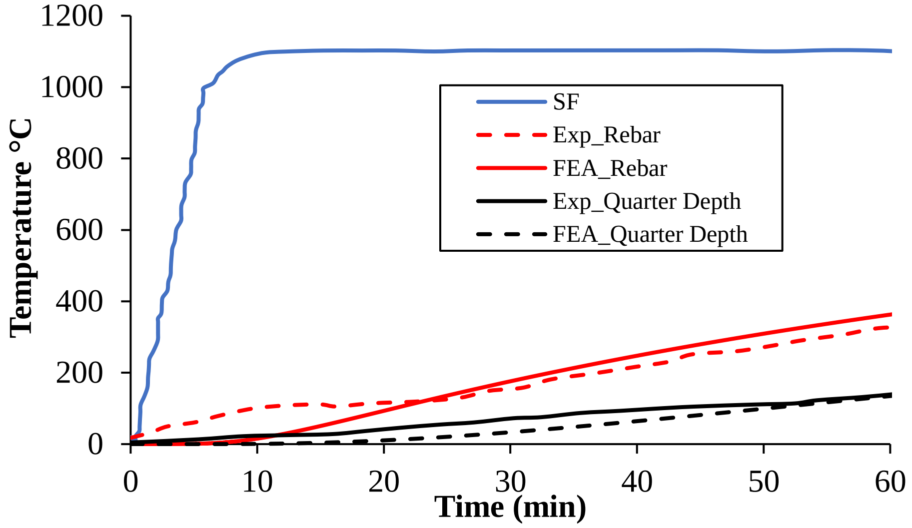


Figure 4.2: Different location temperatures of tested reinforced concrete beam.

4.4 Validation parameter based on Dilation angle

During the validation phase of our study, extensive experimentation was conducted to assess the influence of various dilation angles on the structural response of reinforced concrete beams. The dilation angle, a crucial parameter in our investigation, was examined across a range typically spanning from 20 to 31 degrees. This selection was meticulously made to encompass a diverse spectrum of values, facilitating a comprehensive analysis of its impact on structural behavior. By scrutinizing this broad range, our aim was to discern nuanced variations in beam response under different degrees of expansion, thus augmenting our understanding of their overall efficacy.

In multiple model analyses, dilation angles of 20, 25, and 31 degrees were specifically investigated, while maintaining a constant viscosity of 20%, employing steel grade 400/420, and utilizing a mesh size of 25mm. Figure 4.1 illustrates the variation in dilation angle, denoted by the symbol ψ, with a consistent viscosity of 20%. The primary objective was to ascertain the optimal dilation angle that consistently aligned with the expected structural responses.

Upon thorough analysis of the experimental results, it was determined that a dilation angle of 31 degrees exhibited the most favorable relationship with the desired structural behavior. Consequently, this specific angle was chosen to serve as the standard dilation angle for the beams included in our study. This meticulous selection process ensures that our computational model accurately reflects real-world structural behavior, enhancing the reliability and applicability of our findings in practical engineering scenarios. Figure 4.3 displays the relationship between load and displacement in a validation-based dilation angle scenario. The graph likely illustrates how the load applied to a system corresponds to the resulting displacement, with the dilation angle serving as a validation parameter.

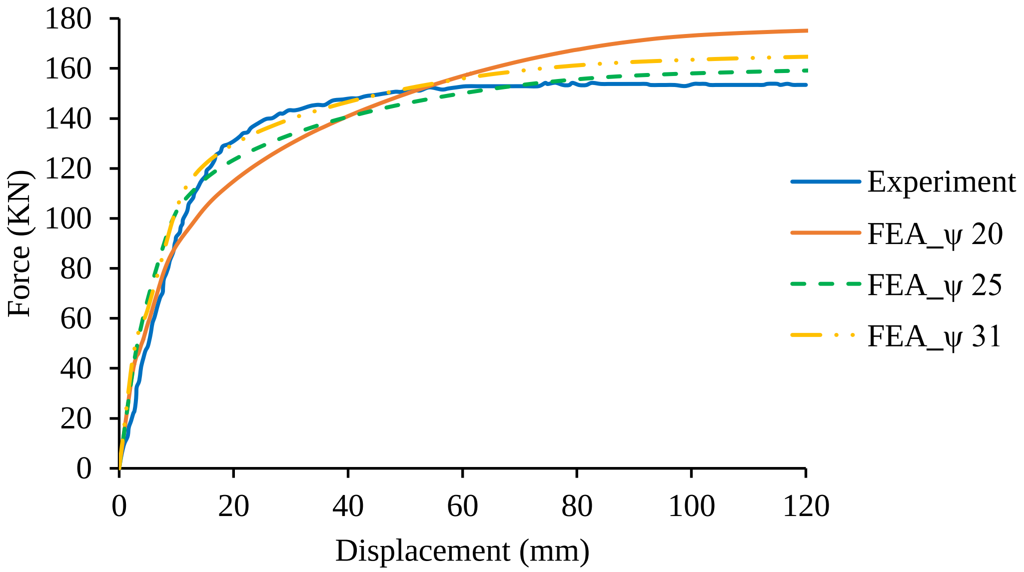


Figure 4.3: Load Vs displacement validation-based dilation angle.

4.5 Viscosity-based validation parameter

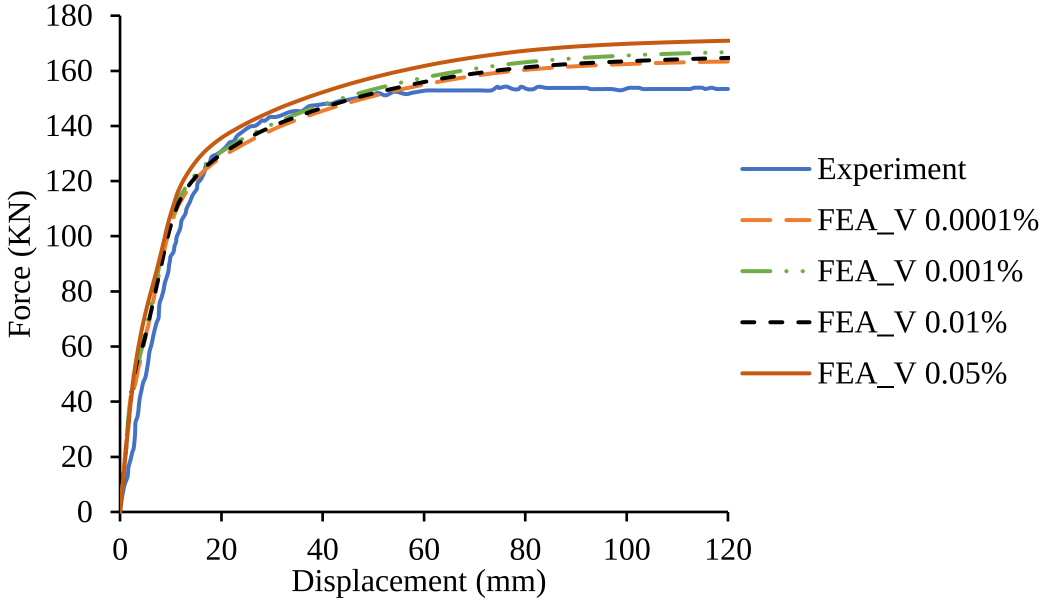
The validation process undertaken in this study aimed to verify that the selected viscosity values accurately reflect empirical data and effectively depict the structural behavior of reinforced concrete beams. Through meticulous documentation of findings and the specifics of each viscosity experiment conducted during the validation phase, a robust foundation for the reliability of the finite element analysis (FEA) model was established.

This investigation delves into the impact of varied viscosity percentages on structural responses across different beam configurations. A systematic approach was adopted to consider viscosity, involving several trials with initial viscosity values set at 0.00001 for the beam, resulting in a meticulous and time-consuming procedure. Subsequent procedures incrementally increased the viscosity value to streamline and expedite the study. Employing an iterative methodology, a viscosity ranges from 0.0001% to 1% was determined, balancing study efficiency with accuracy.

Figure 4.4 depicted herein, vividly showcases the influence of viscosity changes on the structural behavior of beams, with 'V' representing viscosity. A comprehensive log of each viscosity test is appended to provide a reference point. The graph below highlights the optimal viscosity values in conjunction with a dilation angle of 31 degrees, emphasizing this combination as influential in eliciting desired structural responses in the beams.

Through meticulous analysis, the viscosity percentages most suitable for the beam were identified as 0.000001. The chosen mesh size, a critical factor influencing accuracy, remained consistent at 25 millimeters throughout. A thorough examination of viscosity variations may enhance the accuracy of finite element models by ensuring compatibility with other parameters, thereby refining the precision of structural assessments. This rigorous approach not only validates the FEA model but also contributes to advancing the understanding and predictive capabilities of reinforced concrete beam behavior under varying thermal conditions.

A)



b)

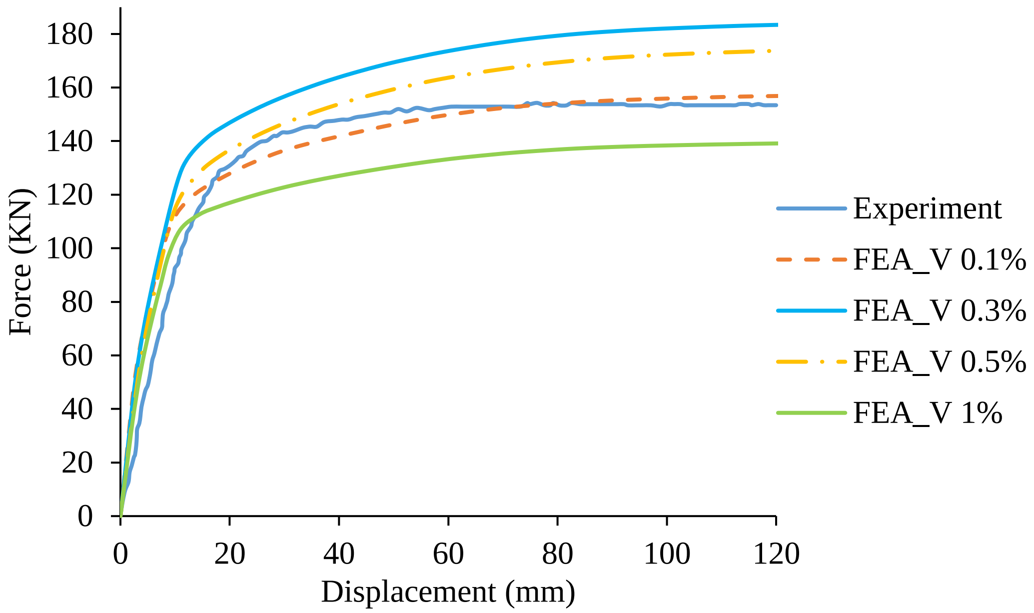


Figure 4.4: Various viscosity in FEA

4.6 Verification of the Mesh in Finite Element Models

Meshing plays a pivotal role in finite element analysis (FEA), serving as the foundation upon which complex structures are discretized into smaller interconnected elements. This division facilitates the creation of a mesh, enabling the mathematical modeling of structural behavior at specific nodes. The quality and size of the mesh significantly influence both the accuracy of results and the computational efficiency of the study. Achieving optimal meshing entails a delicate balance: while finer mesh resolution enhances accuracy, it also increases computational workload, whereas coarser meshing improves computational efficiency at the expense of accuracy. Thus, selecting an appropriate meshing strategy is crucial for obtaining reliable simulations of structural behavior across diverse scenarios.

In our study, six different mesh sizes ranging from 15 to 50 millimeters were employed to investigate their impact on the structural behavior of each beam. Following an exhaustive analysis, it was observed that the outcomes obtained from these varied mesh designs were largely comparable, exhibiting only minor differences. Consequently, a mesh size of 25 millimeters was selected for the beam, as it struck a balance between computational efficiency and result accuracy. This choice, informed by the principle of optimizing efficiency without compromising accuracy, ensures the capture of relevant insights into the structural behavior under investigation.

Figure 4.5 displays the diverse mesh sizes utilized in the study, ranging from M 15mm to M 50mm. This comprehensive exploration of meshing options underscores the meticulous approach taken to validate the computational model and enhance the understanding of reinforced concrete beam behavior. By systematically evaluating the influence of mesh size on structural responses, our study contributes to refining the meshing strategies employed in FEA, thereby improving the reliability and applicability of computational simulations in structural engineering analyses.

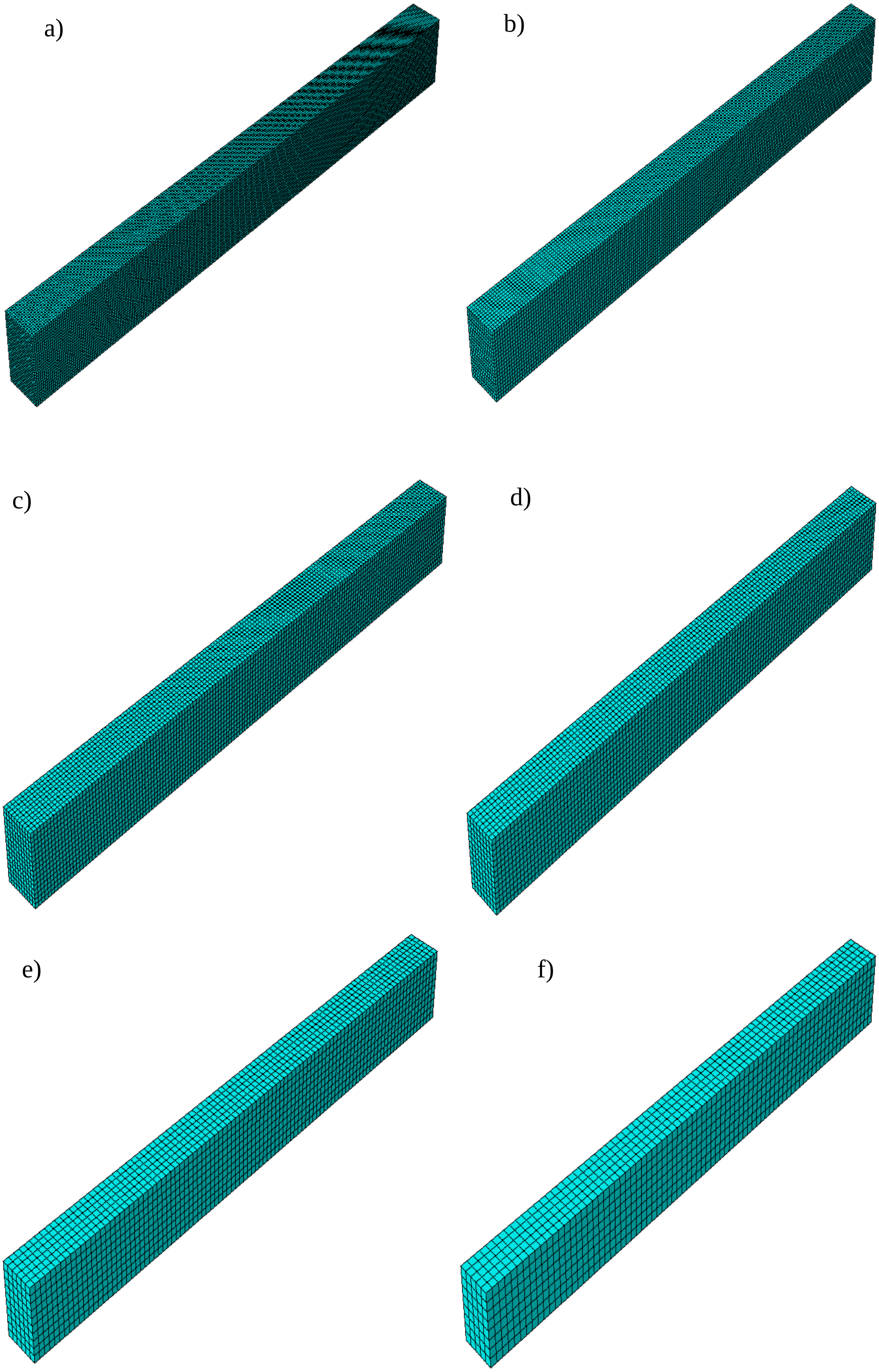


Figure 4.5: Different types of Mesh Size a) M 50 mm b) M 40 mm c) M 30 mm d) M 25mm e) M 20 mm f) M 15 mm.

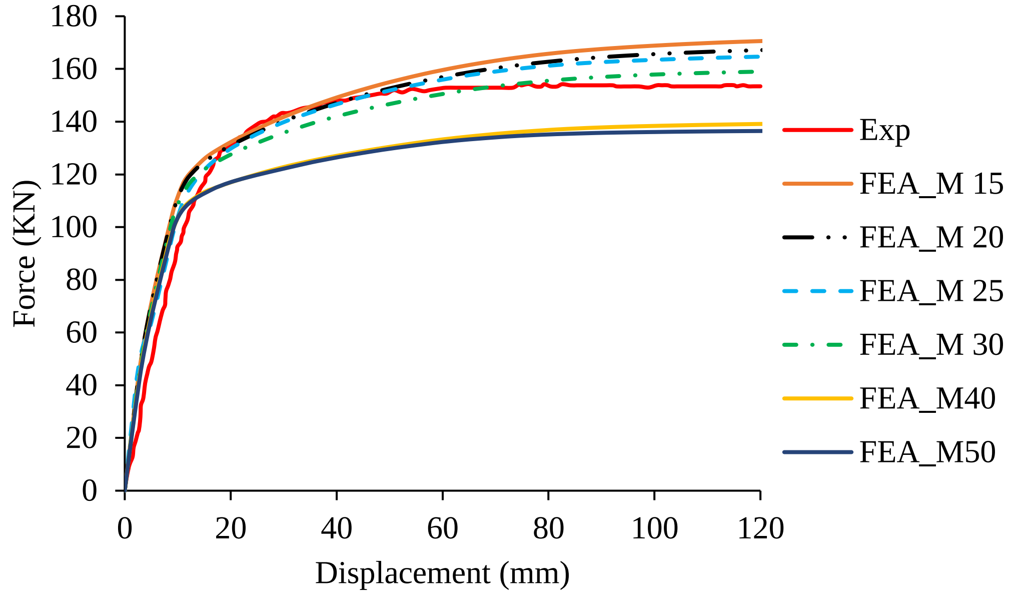


Figure 4.6: RC beam load vs displacement behavior at mesh variation results

The mesh analysis conducted in our investigation unveiled a spectrum of mesh sizes suitable for experimental validation of beam behavior. However, following meticulous consideration, we determined that a standard mesh size of 25 millimeters stands as the optimal choice for the beam under scrutiny. This selection is underpinned by the observation that differences in mesh sizes among beams are marginal, advocating for a uniform approach to meshing. Additionally, the preservation of a constant dilation angle of 31 degrees throughout the procedural phases ensures the sustained consistency of the beams over the duration of the trial. Figure 4.6 illustrates the load versus displacement behavior of an RC (Reinforced Concrete) beam in response to variations in mesh density. This graph likely showcases how different levels of mesh refinement impact the structural response of the RC beam under load.

4.7 Various Validation Assessment

In our investigation, a thorough and systematic analysis was conducted to enhance the accuracy of our assessments regarding reinforced concrete beams. Multiple trials were meticulously performed, aiming to validate the computational model's predictions against empirical data. The Appendix section of our thesis will present a comprehensive compilation of specific findings derived from these trials. It will include detailed comparisons between experimental data and ABAQUS outcomes for various parameters, such as differences in viscosity and reinforcement yield strength. By meticulously reviewing each trial and its corresponding outcomes, this section will provide valuable insights into the reliability and effectiveness of our computational model in simulating the heat transfer behavior of reinforced concrete beams. Through this comprehensive analysis, we aim to contribute to the advancement of structural engineering practices and enhance the understanding of heat transfer phenomena in reinforced concrete structures.

The intricate influence of viscosity on the structural dynamics of reinforced beams has been meticulously explored in this study, with strategic modifications implemented with meticulous attention to detail. This deliberate approach has facilitated a more effective execution of finite element analysis (FEA). The incorporation of viscosity considerations has played a pivotal role in augmenting our confidence in the fidelity and accuracy of the conclusions drawn from the comprehensive simulation results. In the realm of heat transfer within reinforced beams, the integration of viscosity effects significantly impacts the flow characteristics of the material, altering the distribution of thermal energy within the structure. Through FEA, these intricate heat transfer phenomena can be accurately modeled and analyzed, providing valuable insights into the thermal behavior of reinforced beams under various loading conditions. By accounting for viscosity, engineers can better understand the thermal performance of such structures, enabling informed decision-making in design and optimization processes. This research underscores the importance of considering viscosity in structural analysis, particularly in the context of heat transfer, and highlights its implications for the reliability and robustness of engineering assessments conducted through FEA methodologies.

To ensure coherence, it was proven that the value of (Kc) remained consistent at 0.667 throughout all beam. shows that the Figure 4.7 viscosity parameter varies significantly depending on the mesh size used.

Table 4.1: Final Materials Properties

Beam No	**Dilation Angle**	**Eccentricity**	**fb0/fc0**	**Kc**	**Viscosity Parameter**	**Mesh Size (mm)**
B1	31	0.1	1.16	0.667	0.0001%	25

Utilizing the provided material parameters, we meticulously scrutinized the structural characteristics of three distinct reinforced beams, methodically adjusting mesh sizes to elucidate their impact on structural behavior. Employing a systematic methodology, we conducted an exhaustive investigation into the outcomes of finite element analysis, thereby discerning the most suitable mesh size for each beam. The iterative refinement of mesh sizes yielded crucial insights into the influence of this parameter on the accuracy and efficacy of structural simulations. Through this iterative process, we gained a valuable understanding of how variations in mesh size directly affected the overall performance of the beams under consideration. Figure 4.4 visually represents the variation in mesh density for the reinforced concrete beam, depicting the iterative adjustments undertaken during our analysis.

Table 4.2: Trails and Errors for this analysis

Trails	EXP	FEA	Error	Trails	EXP	FEA	Error
J1	153.414	214.586	40%	**J27**	153.414	159.742	4%
J2	153.414	200.408	31%	**J28**	153.414	136.461	11%
J3	153.414	193.163	26%	**J29**	153.414	156.695	2%
J4	153.414	192.785	26%	**J30**	153.414	139.161	9%
J5	153.414	201.759	32%	**J31**	153.414	159.208	4%
J6	153.414	201.141	31%	**J32**	153.414	159.048	4%
J7	153.414	192.583	26%	**J33**	153.414	167.062	9%
J8	153.414	184.681	20%	**J34**	153.414	159.38	4%
J9	153.414	175.117	14%	**J35**	153.414	170.54	11%
J10	153.414	194.261	27%	**J36**	153.414	174.505	14%
J11	153.414	128.58	16%	**J37**	153.414	183.34	20%
J12	153.414	139.101	9%	**J38**	153.414	170.944	11%
J13	153.414	150.906	2%	**J39**	153.414	164.68	7%
J14	153.414	171.736	12%	**J40**	153.414	162.319	6%
J15	153.414	166.956	9%	**J41**	153.414	163.832	7%
J16	153.414	166.947	9%	**J42**	153.414	169.19	10%
J17	153.414	164.528	7%	**J43**	153.414	166.798	9%
J18	153.414	155.672	1%	**J44**	153.414	152.592	1%
J19	153.414	164.353	7%	**J45**	153.414	161.924	6%
J20	153.414	164.343	7%	**J46**	153.414	146.316	5%
J21	153.414	162.982	6%	**J47**	153.414	156.876	2%
J22	153.414	196.279	28%	**J48**	153.414	155.71	1%
J23	153.414	160.87	5%	**J49**	153.414	165.706	8%
J24	153.414	159.162	4%	**J50**	153.414	166.618	9%
J25	153.414	173.674	13%	**J51**	153.414	159.834	4%
J26	153.414	159.153	4%	**J52**	153.414	163.374	6%

Table 4.2: presents a comparison of Trials EXP and FEA Error percentages for different trials labeled J1 to J52. The Trails EXP value remains constant at 153.414 across all trials, while the FEA Error varies, indicating the percentage difference between the Trails EXP and the actual FEA results. The error percentages range from a low of 1% to a high of 40%, suggesting variability in the accuracy of the FEA predictions compared to the Trails EXP values. This table could be used to assess the reliability of FEA simulations in predicting experimental outcomes.

The Finite Element Analysis (FEA) trial conducted in this study yielded promising results when employing specific parameters. Utilizing a mesh size of 25mm, a dilation angle of 31, an eccentricity of 0.1, and a viscosity of 0.0001% produced outcomes deemed satisfactory for further analysis.

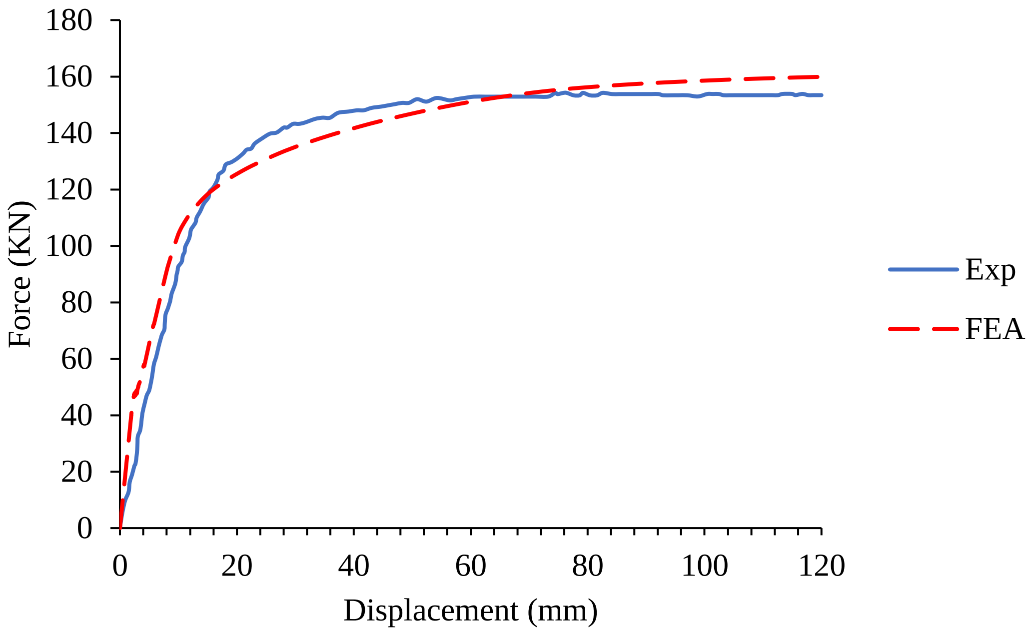


Figure 4.7: RC beam load vs displacement best results

Figure 4.7 presents a comparison between experimental (Exp) and finite element analysis (FEA) results for a reinforced concrete (RC) beam subjected to a load. The graph plots the force applied to the beam (in kilonewtons, KN) against the resulting displacement (in millimeters, mm), showcasing the beam's response to increasing loads.

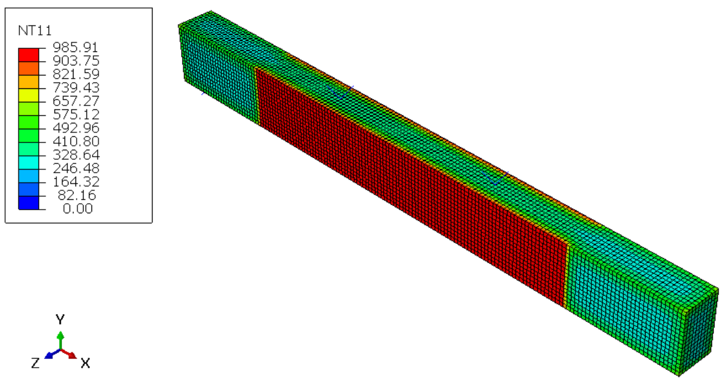
The Exp graph demonstrates the actual behavior of the RC beam under load, indicating a linear relationship initially, followed by non-linear behavior as the beam approaches failure. The FEA graph closely aligns with the experimental results, suggesting that the simulation is well-calibrated and accurately reflects the physical behavior of the beam.

Both graphs exhibit good correlation, especially in the initial linear portion, which is crucial for understanding the beam's elastic behavior. The slight deviations in the later stages are expected due to the complexities of modeling concrete cracking and steel yielding in FEA.

The inclusion of other materials, detailed in the Appendix, further enriches the analysis by allowing for comparison and evaluation of their respective impacts on the FEA results. Such comprehensive examination contributes to a more nuanced understanding of how material properties influence structural behavior, particularly in fire scenarios.

The results obtained from the FEA simulations underscore the importance of selecting appropriate parameters and material properties for accurate and reliable analysis of structural performance, particularly in scenarios involving fire-induced effects. These findings lay a solid groundwork for future research endeavors aimed at enhancing the safety and resilience of structural systems in real-world applications.

a)



b)

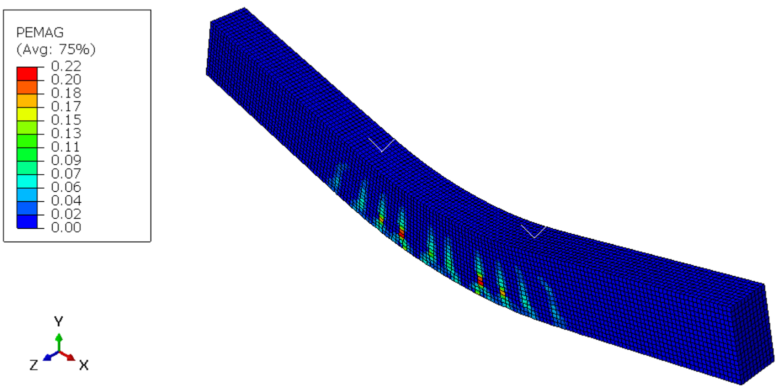


Figure 4.8: Effect of load and temperature after FEA, a) For Temperature, and b) For Displacement

4.8 Summary

Findings from ABAQUS simulations are presented, showing the influence of material properties on the structural behavior of beams under fire scenarios, validated against experimental data.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

The purpose of this research is to conduct a thorough examination of the behavior of reinforced concrete beams, with a specific emphasis on material parameters pertinent to fire and load scenarios, including dilation angle, viscosity, and mesh size. Employing ABAQUS software, a detailed quantitative analysis was conducted, effectively corroborating experimental findings and enhancing comprehension of the intricate interplay among these factors. Precise measurements of the beams facilitated logical comparisons, bolstering the reliability of the study. Successful emulation of the concrete-steel connection in real-world conditions was achieved, with ABAQUS analytical methodology pivotal in modeling diverse scenarios. The study validates the accuracy of finite element models, offering invaluable insights into parameter optimization for future evaluations. Following a comprehensive investigation, it was determined that viscosity values of 0.0001, 0.00001, and 0.000001, alongside a dilation angle of 31 and a mesh size of 25 mm, yielded optimal outcomes for the beams under fire and load conditions.

Here are some important things we learned from this study:

i. This comparison revealed a striking consistency between the results obtained from the finite element simulation and the actual findings of the experiment.

ii. Utilizing a viscosity range of 0.001 to 0.000001 in the finite element model as a concrete damage material parameter, after multiple trials and error it was verified that a viscosity of 0.000001 yielded satisfactory outcomes for this analysis.

iii. The analysis yields satisfactory results for the beam with a dilation angle of 31 degrees. The utilization of a dilation angle range of 20 to 31 in the finite element model as a concrete damage material parameter was found to be both reliable and consistent with the experimental findings, as corroborated by finite element analysis (FEA).

iv. Mesh sizes ranging from 20 mm to 50 mm were utilized in modeling the beam. However, distinct optimal mesh sizes were determined through finite element analysis (FEA), with a 25 mm mesh size being identified as the most suitable for accurate simulations.

v. The validation approach shows good agreement with experimental test results for both thermocouple temperature during the fire and post-fire capacity of the reinforced concrete beam.

5.2 Recommendation

In future investigations concerning reinforced concrete beams, it is advisable to adopt viscosity and dilation angle values analogous to those discerned as optimal in this study. This recommendation is grounded in the identification of ideal parameters.

Researchers are encouraged to consider the following facets for prospective inquiries:

1. To ensure material properties for the materials involved, especially those that will be exposed to fire. This includes thermal conductivity, specific heat capacity, thermal expansion coefficient, and mechanical properties at elevated temperatures.
2. Incorporate heat transfer analysis into your FEA model to simulate the temperature distribution within the structure during a fire event. This helps in understanding how the heat propagates and affects different parts of the structure.
3. Perform transient analysis to simulate the dynamic behavior of the structure as it heats up and cools down during a fire event. This involves analyzing how temperature changes with time and how it affects the mechanical response of the structure.
4. Model the fire loading accurately based on the expected fire scenario. This includes factors such as fire intensity, duration, and spatial distribution of heat flux.
5. Perform mesh sensitivity analysis to ensure that the FEA results are not significantly affected by the mesh size. This helps in obtaining accurate and reliable results.

REFERENCES

Agrawal, V. K. (2015). Critical Factors Governing the Residual Response of Reinforced Concrete Beams Exposed to Fire. CrossMark.

Ahmadul Hassan, D. (2024, March 04). 2600 buildings in Dhaka at risk of fire. Retrieved from Prothom Alo: https://en.prothomalo.com/bangladesh/city/tcs9i5s4hc

Bin Cai, B. Z. (2019). A new reliability analysis approach for the flexural capacity of postfire reinforced concrete beams retrofitted with CFRPs.

Bin Cai1, G.-l. P. (2020). Prediction of the Postfire Flexural Capacity of RC. American Society of Civil Engineers.

Chang-Jiu Jiang, L.-Z. L.-D.-H. (2018). Experimental study on the residual shear capacity of fire-damaged reinforced concrete frame beams and cantilevers. Fire Safety Journal.

Dafni Pantousa, T. K. (2022). Numerical Investigation of the Post-Fire Performance of. MDPI stays neutral.

E.G. Choi, Y. S. (2011). The structural behavior and simplified thermal analysis of normal-strength and. Engineering Structures.

Homer, J. M. (2022, March 23). Top 6 Fire-resistant Building Materials. Retrieved from HowStuffWorks: https://home.howstuffworks.com/home-improvement/construction/materials/5-fire-resistant-building-materials.htm#:~:text=4%3A%20Concrete&text=It%20is%20noncombustible%20and%20has,and%20protect%20steel%20from%20fire.

Hossain, K. (2024, March 28). Why are fire incidents increasing in Bangladesh? Retrieved from Dhaka Tribune: https://www.dhakatribune.com/bangladesh/342889/why-are-fire-incidents-increasing-in-bangladesh

Khaliq, W. (2012). PERFORMANCE CHARACTERIZATION OF HIGH PERFORMANCE CONCRETES . Civil Engineering.

Kodur, M. B. (2009). Response of Restrained Concrete Beams under Design Fire Exposure. JOURNAL OF STRUCTURAL ENGINEERING.

Kodur, V. K., & Sultan, M. A. (2003). Effect of temperature on thermal properties of high-strength concrete. NRC Publications.

Mousa, M. I. (2015). Flexural behaviour and ductility of high strength. Alexandria Engineering Journal.

Nassif, A. (2005). Postfire full stress–strain response of fire-damaged concrete. John Wiley & Sons, Ltd.

Rui Sun, B. X. (2018). Modeling of Reinforced Concrete Beams Exposed to Fire by. Hindawi.

Saad, M. (2020, February 10). Record number of fires last year: 24,074 incidents, Tk 330cr loss. Retrieved from The Daily Star: https://www.thedailystar.net/frontpage/news/fire-incidents-spike-1865701

Structures, H.-T. P. (2010). High-Temperature Properties of Steel for Fire Resistance Modeling of Structures. ResearchGate.

V. K. R. Kodur, M. B. (2010). An approach for evaluating the residual strength of fire-exposed RC beams. Michigan State University.

V.K.R. Kodur, A. A. (2017). Effect of temperature induced bond degradation on fire response of reinforced concrete beams. Engineering Structures.

V.K.R. Kodur, B. Y. (2013). A simplified approach for predicting temperature in reinforced concrete members exposed to standard fire. Fire Safety Journal.

Venkatesh K. R. Kodur, F. (2020). Estimating Postfire Residual Capacity of Heavily Damaged Concrete Members. ACE.

Venkatesh Kodur, D. H. (2017). Residual response of reinforced concrete columns exposed to design. Procedia Engineering.

Venkatesh Kodur, F. W. (2011). Effect of Temperature on Thermal Properties of Different Types of High-Strength Concrete. JOURNAL OF MATERIALS IN CIVIL ENGINEERING.

Venkatesh Kodura, D. H. (2017). Residual response of reinforced concrete columns exposed to design . Procedia Engineering.

W.Y. Gao 1, J.-G. D. (2013). Finite element modeling of reinforced concrete beams exposed to fire. Engineering Structures.

W.Y. Gao, J.-G. D. (2013). Finite element modeling of reinforced concrete beams exposed to fire. Engineering Structures.

Wei Wang, C. L. (2017). Effects of stress and high temperature on the carbonation resistance of ly ash concrete. Construction and Building Materials.

Xiuling Li, Y. B. (2017). Construction and Building Materials.

APPENDIX

The Tables below show all the material properties we used.

Table A. 1: Specific heat of concrete.

SP heat(J/kg/k)	SP heat(N.mm/T/k)	Temp
900.00	9.00E+08	20
900.00	900000000	100
1000.00	1000000000	200
1050.00	1050000000	300
1100.00	1100000000	400
1100.00	1100000000	500
1100.00	1100000000	600
1100.00	1100000000	700
1100.00	1100000000	800
1100.00	1100000000	900
1100.00	1100000000	1000
1100.00	1100000000	1100
1100.00	1100000000	1200

Table A. 2: Conductivity of concrete.

Conductivity(w/mk)	Conductivity(mw/mm.k)	Temp
1.36	1.36	0
1.33	1.33	20
1.23	1.23	100
1.11	1.11	200
1.00	1.00	300
0.91	0.91	400
0.82	0.82	500
0.75	0.75	600
0.69	0.69	700
0.64	0.64	800
0.60	0.60	900
0.57	0.57	1000
0.55	0.55	1100
0.55	0.55	1200

Table A. 3: Specific heat of steel.

SP heat(J/kg/k)	SP heat(N.mm/T/k)	Temp
439.80	439801760	20
487.62	487620000	100
529.76	529760000	200
564.74	564740000	300
605.88	605880000	400
666.50	666500000	500
760.22	760217391.3	600
1008.16	1008157895	700
5000.00	5000000000	735
803.26	803260869.6	800
650.00	650000000	900
650.00	650000000	1000
650.00	650000000	1100
650.00	650000000	1200

Table A. 4: Conductivity of steel.

Conductivity(w/mk)	Conductivity(mw/mm.k)	Temp
54	54	0
53.3	53.3	20
50.7	50.7	100
47.3	47.3	200
44	44	300
40.7	40.7	400
37.4	37.4	500
34	34	600
30.7	30.7	700
27.3	27.3	800
27.3	27.3	900
27.3	27.3	1000
27.3	27.3	1100
27.3	27.3	1200

Table A. 5: Multiple trials for temperature validation.

Job Name	Conductivity	Film Coefficient	Radiation/Emissivity	Ambient Temperature	Amplitudes
J1	Upper limit	0.025	1	0	F2
J2	Lower limit	0.025	1	0	F2
J3	Upper limit	0.05	1	0	F2
J4	Upper limit	0.1	1	0	F2
J5	Upper limit	0.1	0.8	1	F2
J6	Upper limit	0.025	0.8	1	F2
J7	Lower limit	0.025	0.8	1	F2
J8	Lower limit	0.025	0.8	1	F5_90%
J9	Lower limit	0.025	0.8	1	F6_95%

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Table A. 6: Trail Information.

Job Name	D Angle	Viscosity	Kc	Concrete Type	Steel Type	Fc	Fy	Fy(Shear)	Elastic Factor	Mesh
J1	31	0.00001	0.667	Chang (800)	Basic	59.2	420	280	0.33	25
J2	31	0.00001	0.667	Chang (800)	Basic	59.2	420	280	0.33	25
J3	31	0.00001	0.667	Chang (800)	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J4	31	0.00001	0.667	V2	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J5	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J6	20	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J7	31	0.000000001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J8	20	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	400	280	0.33	25
J9	20	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	380	280	0.33	25
J10	20	0.00001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	380	280	0.33	25
J11	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J12	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J13	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25

J14	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J15	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J16	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J17	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J18	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J19	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J20	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J21	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.5	25
J22	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.5	25
J23	31	0.01	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.5	25
J24	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.5	25
J25	25	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J26	31	0.005	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J27	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J28	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J29	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	50
J30	31	0.007	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	50
J31	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	40
J32	31	0.007	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	40
J33	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	30
J34	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	20
J35	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	20
J36	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	15
J37	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25

J38	31	0.003	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J39	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J40	31	0.0005	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J41	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J42	31	0.00001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J43	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	20
J44	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J45	31	0.00001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J46	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	30
J47	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	30
J48	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	40
J49	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	40
J50	31	0.0001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	50
J51	31	0.001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	50
J52	31	0.000001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	420	280	0.33	25
J53	31	0.000001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	59.2	400	280	0.33	25
J54	31	0.000001	0.667	V2_CS 0.9	Residual_Heat Data Generator(Steel)	52	420	280	0.33	25