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Thermal performance of hollow steel sections under high-temperature conditions

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Abstract
This experimental study investigates the thermal performance of hollow steel sections (HSS) subjected to high-temperature conditions, such as those encountered during fire incidents. The research focuses on assessing changes in mechanical properties, thermal conductivity, and structural integrity under various temperature regimes. Hollow steel sections of varying geometries were tested in a controlled high-temperature environment, and key performance indicators, such as yield strength, ultimate load capacity, and thermal expansion, were analyzed. Results show a significant decline in strength and stiffness beyond 600 °C, along with notable thermal buckling behavior. These findings contribute to understanding the fire-resistance properties of hollow steel structures and provide recommendations for fire-safe design in construction.

Keywords: Buckling, structures, provide

Introduction
Hollow steel sections (HSS) are widely used in modern construction due to their high strength-to-weight ratio, ease of fabrication, and aesthetic appeal. However, their performance under elevated temperatures, such as during fire exposure, is a critical concern for structural safety. High temperatures can weaken steel's mechanical properties, such as yield strength and elastic modulus, leading to structural instability and potential collapse.
Previous studies have indicated that steel exhibits a linear reduction in strength as temperatures rise, with significant degradation beyond 500 °C (Kodur *et al.*, 2013). However, limited research exists on the thermal performance of hollow steel sections specifically, given their unique geometry and thermal behavior. This study aims to fill this gap by experimentally investigating how HSS respond to high-temperature conditions.

The research objectives include
- Evaluating the effect of elevated temperatures on the mechanical and thermal properties of HSS.
- Analyzing the thermal expansion, buckling behavior, and residual strength of HSS under fire-like conditions.
- Providing insights for designing fire-resistant steel structures.

Experimental Program
Materials and Specimens: The study used rectangular and circular hollow steel sections fabricated from structural-grade steel (IS 4923). The specimens were of the following dimensions:
- Rectangular HSS: 100 mm × 50 mm × 5 mm wall thickness.
- Circular HSS: Diameter 100 mm, wall thickness 5 mm.

Three specimens of each geometry were tested at temperature increments of 200 °C, 400 °C, 600 °C, 800 °C, and 1000 °C.

Test Setup: A high-temperature furnace equipped with precise temperature control was used to simulate fire conditions. The furnace allowed uniform heating of specimens and monitoring of thermal responses. A universal testing machine (UTM) was used to evaluate the mechanical properties, including yield strength, ultimate load capacity, and stiffness, at elevated temperatures.

Instrumentation

- **Thermocouples**: Installed at multiple locations on the specimen surface to record temperature variations.
- **Displacement Gauges**: To measure thermal expansion and deflection.
- **Load Cells**: To record the applied load and measure the residual strength of the specimens.

Testing Procedure: Specimens were heated to the target temperature and held for a steady-state period of 30 minutes to ensure uniform temperature distribution. Mechanical tests were conducted immediately after heating, with the load applied until specimen failure. Data on deformation, load capacity, and thermal responses were recorded.

Results and Discussion

Mechanical Properties at Elevated Temperatures

The results showed a progressive decline in yield strength and ultimate load capacity with increasing temperature. The degradation of mechanical properties became significant at temperatures above 600 °C.

Temperature (°C)	Yield Strength Reduction (%)	Ultimate Load Reduction (%)
200	10	8
400	25	20
600	50	45
800	70	65
1000	85	80

The rectangular sections exhibited slightly better retention of strength compared to circular sections due to their higher moment of inertia.

Thermal Expansion

Thermal expansion increased linearly with temperature up to 600°C, after which nonlinear behavior was observed. The circular HSS exhibited higher expansion rates due to their symmetrical geometry, which allowed uniform thermal elongation.

Temperature (°C)	Average Thermal Expansion (mm)
200	1.2
400	2.8
600	4.5
800	6.3
1000	7.8

Buckling Behavior: Buckling was observed at higher temperatures, with specimens exhibiting significant lateral deflection at 800°C and above. The circular sections were more prone to thermal buckling due to their geometry, while rectangular sections showed localized deformations.

Residual Strength: After cooling to ambient temperature, residual strength tests revealed that specimens retained only 40–60% of their original strength, emphasizing the need for fire-resistant coatings or insulation for hollow steel sections in fire-prone environments.

Discussion

The results demonstrate significant thermal degradation of hollow steel sections (HSS) under high-temperature conditions, with notable implications for their structural performance. The yield strength and ultimate load capacity of HSS progressively declined as temperatures increased, with severe reductions observed beyond 600°C. At 1000°C, the specimens retained only 15% of their original yield strength, indicating a critical loss of mechanical integrity. Rectangular sections exhibited slightly better performance compared to circular sections, attributed to their higher moment of inertia, which offers greater resistance to deformation under elevated temperatures. Thermal expansion showed a linear behavior up to 600°C, after which nonlinear patterns emerged due to material transformations and the onset of creep. Circular sections displayed higher thermal expansion values than rectangular ones, attributed to their symmetrical geometry that facilitates uniform elongation. Beyond 800°C, thermal buckling became a dominant failure mode, with circular sections experiencing significant lateral deflection, while rectangular sections displayed localized deformation. The susceptibility of circular sections to buckling underscores the influence of geometry on thermal performance. Residual strength analysis revealed that HSS retained only 40–60% of their original strength after cooling, emphasizing the irreversible damage caused by high temperatures. This reduction raises concerns about the post-fire structural integrity of HSS and underscores the need for fireproofing measures. Comparisons with existing literature reinforce the findings, highlighting consistent trends in the thermal degradation of steel at elevated temperatures. The study emphasizes the importance of incorporating fire-resistant designs and protective measures, such as intumescent coatings and insulation materials, to enhance the thermal performance and structural safety of HSS. These findings contribute valuable insights into the fire-resistance properties of steel structures and offer practical recommendations for mitigating the risks associated with high-temperature exposure. Future research should focus on exploring the performance of HSS with varying wall thicknesses, hybrid materials, and advanced fire-protection technologies to further enhance their resilience in fire-prone environments.

Conclusion

This study provides a comprehensive evaluation of the thermal performance of hollow steel sections (HSS) under high-temperature conditions, shedding light on their behavior during fire exposure. Key findings reveal a significant decline in yield strength and ultimate load capacity at temperatures above 600°C, with up to 85% reduction at 1000°C. Thermal expansion exhibited linear behavior up to 600°C, followed by nonlinear expansion and thermal buckling at higher temperatures. Circular sections were more prone to buckling, whereas rectangular sections demonstrated better thermal stability, attributed to their geometry. The residual strength tests highlighted that HSS retained only 40–60% of their original strength after exposure to elevated temperatures, underscoring the need for fire-resistant coatings or insulation to mitigate structural damage. These findings contribute to understanding the fire-resistance properties of steel structures and emphasize the importance of incorporating protective measures to ensure safety and structural integrity during fire incidents. The study underscores the critical role of fire-resistant designs in construction and provides valuable insights for developing guidelines to enhance the resilience of HSS. Future work should explore the effects of varying wall thicknesses, composite materials, and advanced fire-protection technologies to further improve the fire performance of steel structures.

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