BEHAVIOUR OF BAMCRETE WALL PANELS AT ELEVATED TEMPERATURE

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by

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Dedicated to

My Beloved Daughter

Raghavi

Certificate

This is to certify that the thesis entitled **"Behaviour of Bamcrete Wall Panels at Elevated Temperature"** submitted by **Anu Bala (2016CEZ8438)** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** in Civil Engineering is a bonafide record of research work carried out by her under our supervision. The thesis work, in our opinion, has reached the requisite standard of fulfilling the requirements for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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Anu Bala

Abstract

Bamboo is a naturally occurring, low-cost composite material that is approximately nine times lighter than steel, but the tensile strength-to-weight ratio is approximately 5 to 6 times greater than steel. Concrete walling system with bamboo reinforcement in the form of round culms, or woven strips has higher flexural strength, lighter in weight, and is more economical as compared to conventional brick walling systems. There are various issues with bamboo-based concrete elements associated with service conditions that undermine their capability for structural applications. Water absorption is the major issue with bamboo reinforcements in concrete where bamboo absorbs the moisture and expands during casting and at the end of curing, bamboo shrinks back to the original geometry. This cyclic expansion and contraction of bamboo reinforcement result in voids and adversely affect the bond strength, leading to cracking in concrete. The casting of wall panels having bamboo reinforcement in multiple layers is also a challenging task since the filling of concrete in congested areas is very difficult. Fireproofing is another major challenge for bamboo-based constructions. Bamboo is a combustible material, that undergoes pyrolysis above 150 ^{o}C, and loses mass and strength at elevated temperatures. Therefore, assessing the performance of bamboo-reinforced concrete elements at elevated temperatures is a significant aspect of designing fireproof and durable structural elements.

Based on the research gaps and research opportunities available, the present study has proposed to develop bamboo-based cement-mortar panels also named "Bamcrete panels" using twin layers of weaved bamboo strips with an intermediate core area. Twelve sets of Bamcrete panels were designed and fabricated using different combinations of parameters namely; (a) bamboo mesh treatment (b) core material, and (c) material for outer surface covering. To improve the strength and quality of panels, bamboo mesh was treated by (i) coating with cement

paste (ii) wrapping with wire mesh, and (iii) coating with epoxy followed by sprinkling of sand. Four types of core materials were used for Bamcrete panels (1) Fiber-reinforced SCM (2) Styrofoam sheet (3) half-split bamboo filled with sand, and (4) rubberized mortar supported with chicken wire mesh. To overcome the problem of insufficient filling of narrow gaps in weaved bamboo strips, optimal mix designs of fibre-reinforced self-compacting mortar (SCM) were determined for the casting of Bamcrete panels. The blending of fly ash (FA) up to 25% imparted the lubricating effect in the SCM mix, thus, improving the workability and reducing the demand for admixture. The intrusion of fibers (glass wool fibers and Recron fibers) has increased the cohesiveness of the SCM mix resulting in a decrease in slump flow, v-funnel flow speed, increased yield stress, and plastic viscosity. The influence of effective w/c ratio on the rheology of fresh SCM mix is opposite to fiber-reinforcement. The compressive strength of SCM samples has decreased with the addition of glass wool fibers (GWF), whereas the intrusion of GWF has a positive impact on the flexural strength (FS) of SCM. Heating the GWF-reinforced SCM samples to the temperature of 800°C resulted in the severe loss of CS and FS ranging from 45% to 65%. The addition of Recron Fibers (RF) has resulted in higher porosity in the SCM microstructure, thus CS has decreased however, the addition of Recron Fiber has improved the FS by delaying the crack propagation into the SCM matrix. The addition of Recron Fibers has proven to be beneficial in improving the CS and FS of SCM specimens with heating up to 400°C. With further continuous heating of SCM specimens up to the temperatures of 600°C and 800°C, there was a rapid fall in CS and FS. The heat-resisting paint (HRP) coating has created a strong thermal barrier against the external heat to protect the SCM specimens, as a results, there was negligible change in CS and FS post-heating up to the temperatures of 800°C. The addition of Fibers was useful to avoid the explosive spalling in SCM up to the heating temperatures of 800°C. Materials for the outer covering of Bamcrete panels were fixed as (a) SCM reinforced with GWF of 0.5%, and (b) SCM reinforced with RF of 0.2%.

Thermal properties were determined for Bamcrete panels considering steady state heat conduction state. The lowest thermal conductivity (0.11 to 0.13 W/mK) was reported for the panels having Styrofoam sheet as a core material, whereas Bamcrete panels having SCM as a core material have shown the highest thermal conductivity (0.66 and 0.71 W/mK) among all the fabricated Bamcrete panels. Rebound hammer test results showed that the compressive strength of Bamcrete panels varies from 25 MPa to 44 MPa. Bamcrete panels with Styrofoam as a core material have the lowest compressive strength, whereas Bamcrete panels having bamboo mesh wrapped with wire mesh and Fiber reinforced SCM as a core material possessed the highest compressive strength. Thus, the core material has a significant effect on the thermal properties of Bamcrete panels.

The Bamcrete panels were tested under concentrated load at elevated temperatures up to 600°C during fire conditions. The highest load-bearing capacity or shear strength was possessed by the Bamcrete panel (no. 9) having bamboo mesh wrapped with wire mesh and Fiber reinforced SCM as a core material, whereas the panel (no. 2) having bamboo mesh coated with cement slurry and Styrofoam sheet as a core material has lowest strength at ambient temperature as well as at an elevated temperature of 600°C. The highest load taken by the panel at ambient and 600°C was 113 kN and 82 kN, respectively. Visual inspection of Bamcrete panels revealed that the Styrofoam sheet was burnt out during testing at 400°C. No spalling had occurred in any of the panels and there was no charring of weaved bamboo mesh during testing up to the temperatures of 500°C. However, during testing at the temperature of 600°C, the weaved bamboo mesh was charred in most of the panels except for panel no. 9. The coating of heat-resistant paint (HRP) on Bamcrete panels was found very significant in controlling the strength loss at elevated temperatures. Thus, HRP-coated Bamcrete panels can be considered as a sustainable and efficient material for a fireproof building. The current findings will help to popularize the bamboo-based pre-cast structures and will increase the demand for bamboo, provide more diversity to agricultural production, and stimulate the local economy.

Keywords

Bamboo, Bamcrete Panels, Self -Compacting Mortar, Fly Ash, Glass Wool Fiber, Recron Fiber, Durability, Elevated Temperatures, Mechanical Properties, Thermal Conductivity, Rebound Hammer Test, Heat Resistant Paint-Coating.

सार

बांस एक प्राकृतिक रूप से पाया जाने वाला, कम लागत वाला मिश्रित पदार्थ है जो स्टील की तुलना में लगभग नौ गुना हल्का है, लेकिन वजन के अनुपात में तन्य शक्ति स्टील की तुलना में लगभग 5 से 6 गुना अधिक है। गोल पुलिया या बुनी हुई पट्टियों के रूप में बांस के सुदृढीकरण के साथ कंक्रीट की दीवार प्रणाली में पारंपरिक ईंट की दीवार प्रणाली की तुलना में अधिक लचीली ताकत, वजन में हल्का और बहुत किफायती होता है। सेवा शर्तों से जुड़े बांस-प्रबलित कंक्रीट तत्वों के साथ कई मुद्दे हैं जो संरचनात्मक अनुप्रयोगों के लिए उनकी क्षमता को कमजोर करते हैं। कंक्रीट में बांस के सुदृढीकरण के साथ जल अवशोषण प्रमुख मुद्दा है जहां बांस नमी को अवशोषित करता है और ढलाई के दौरान फैलता है और इलाज के अंत में, बांस मूल ज्यामिति में वापस सिकुड़ जाता है। बांस सुदृढीकरण के इस चक्रीय विस्तार और संकुचन के परिणामस्वरूप रिक्त स्थान बन जाते हैं और बंधन शक्ति पर प्रतिकूल प्रभाव पड़ता है, जिससे कंक्रीट में दरारें पड़ जाती हैं। कई परतों में बांस के सुदृढीकरण वाले बीआरसी दीवार पैनलों की ढलाई भी एक चुनौतीपूर्ण कार्य है क्योंकि भीड़भाड़ वाले क्षेत्रों में कंक्रीट भरना बहुत मुश्किल है। बांस-आधारित निर्माणों के लिए अग्निरोधी एक और बड़ी चुनौती है। बांस एक ज्वलनशील पदार्थ है, 150 डिग्री सेल्सियस से ऊपर पायरोलिसिस से गुजरता है और ऊंचे तापमान पर द्रव्यमान और ताकत खो देता है और इसलिए, ऊंचे तापमान पर बांस प्रबलित कंक्रीट तत्वों के प्रदर्शन का आकलन करना अग्निरोधक और टिकाऊ संरचनात्मक तत्वों को डिजाइन करने का एक महत्वपूर्ण पहलू है।

उपलब्ध अनुसंधान अंतरालों और अनुसंधान अवसरों के आधार पर, वर्तमान अध्ययन में एक मध्यवर्ती कोर क्षेत्र के साथ बुनी हुई बांस की पट्टियों की जुड़वां परतों का उपयोग करके बांस-आधारित कंक्रीट पैनल विकसित करने का प्रस्ताव किया गया है, जिसे "बैमक्रीट पैनल" भी कहा जाता है। Bamcrete पैनलों के बारह सेट मापदंडों के विभिन्न संयोजनों का उपयोग करके डिजाइन और निर्मित

किए गए थे; (ए) बांस जाल उपचार (बी) कोर सामग्री, और (सी) बाहरी सतह को कवर करने के लिए सामग्री। पैनलों की मजबूती और गुणवत्ता में सुधार करने के लिए, बांस की जाली को (i) सीमेंट पेस्ट के साथ कोटिंग करके (ii) तार की जाली के साथ लपेटकर, और (iii) एपॉक्सी के साथ कोटिंग के बाद रेत छिड़क कर उपचारित किया गया। Bamcrete पैनलों के लिए चार प्रकार की मुख्य सामग्रियों का उपयोग किया गया था (1) फाइबर-प्रबलित SCM (2) स्टायरोफोम शीट (3) रेत से भरा आधा-विभाजित बांस, और (4) चिकन तार जाल के साथ समर्थित रबरयुक्त मोर्टार। बुनी हुई बांस की पट्टियों में संकीर्ण अंतरालों को अपर्याप्त भरने की समस्या को दूर करने के लिए, बैमक्रीट पैनलों की ढलाई के लिए सेल्फ-कॉम्पैक्टिंग मोर्टार (एससीएम) का इष्टतम मिश्रण डिजाइन निर्धारित किया गया था। 25% तक फ्लाई ऐश (एफए) के मिश्रण ने एससीएम मिश्रण में चिकनाई प्रभाव प्रदान किया, इस प्रकार, कार्यशीलता में सुधार हुआ और मिश्रण की मांग कम हो गई। फाइबर (ग्लास वूल फाइबर और रेक्रॉन फाइबर) की घुसपैठ ने एससीएम मिश्रण की एकजुटता को बढ़ा दिया है जिसके परिणामस्वरूप स्लंप प्रवाह, वी-फ़नल प्रवाह गति में कमी आई है और उपज तनाव और प्लास्टिक चिपचिपाहट में वृद्धि हुई है। ताजा एससीएम मिश्रण की रियोलॉजी पर प्रभावी डब्ल्यू/सी अनुपात का प्रभाव फाइबर प्रबलित एससीएम के विपरीत है। ग्लास वूल फाइबर (जीडब्ल्यूएफ) के शामिल होने से एससीएम नमूनों की संपीड़न शक्ति कम हो गई है, जबकि जीडब्ल्यूएफ की घुसपैठ का एससीएम की लचीली ताकत (एफएस) पर सकारात्मक प्रभाव पड़ता है। जीडब्ल्यूएफ-प्रबलित एससीएम नमूनों को 800 डिग्री सेल्सियस के तापमान तक गर्म करने के परिणामस्वरूप 45% से 65% तक सीएस और एफएस की गंभीर हानि हुई। रेक्रॉन फाइबर (आरएफ) को जोड़ने से एससीएम माइक्रोस्ट्रक्चर में उच्च सरंध्रता आ गई है, इस प्रकार सीएस में कमी आई है, हालांकि, रेक्रॉन फाइबर के जुड़ने से एससीएम मैट्रिक्स में दरार प्रसार में देरी करके एफएस में सुधार हुआ है। 400 डिग्री सेल्सियस तक गर्म करने पर एससीएम नमूनों के सीएस और एफएस में सुधार करने के लिए रेक्रॉन फाइबर को शामिल करना फायदेमंद साबित हुआ है। एससीएम नमूनों को 600 डिग्री सेल्सियस और 800 डिग्री सेल्सियस के तापमान तक लगातार गर्म करने से सीएस और एफएस में तेजी से गिरावट आई। एससीएम

में 800 डिग्री सेल्सियस के ताप तापमान तक विस्फोटक फैलने से बचने के लिए फाइबर को जोड़ना उपयोगी था। बाहरी आवरण क्षेत्र के लिए सामग्री इस प्रकार तय की गई थी (ए) एससीएम 0.5% के जीडब्ल्यूएफ के साथ प्रबलित, और (बी) एससीएम 0.2% के आरएफ के साथ प्रबलित। गर्मी प्रतिरोधी पेंट (एचआरपी) कोटिंग ने एससीएम नमूनों की सुरक्षा के लिए बाहरी गर्मी के खिलाफ एक मजबूत थर्मल बाधा बनाई है, इस प्रकार 800 डिग्री सेल्सियस के तापमान तक गर्म होने के बाद सीएस और एफएस में नगण्य परिवर्तन हुआ।

स्थिर अवस्था ऊष्मा चालन अवस्था को ध्यान में रखते हुए Bamcrete पैनलों के लिए थर्मल गुण निर्धारित किए गए थे। मुख्य सामग्री के रूप में स्टायरोफोम शीट वाले पैनलों के लिए सबसे कम तापीय चालकता (0.11 से 0.13 W/mK) की सूचना दी गई थी, जबकि कोर सामग्री के रूप में SCM वाले Bamcrete पैनलों ने सभी के बीच उच्चतम तापीय चालकता (0.66 और 0.71 W/mK) दिखाई है। निर्मित Bamcrete पैनल। रिबाउंड हैमर परीक्षण के परिणामों से पता चला कि Bamcrete पैनलों की संपीड़न शक्ति 26 MPa से 38 MPa तक भिन्न होती है, जो दर्शाता है कि पैनलों की गुणवत्ता 'अच्छी' श्रेणी में आती है। मुख्य सामग्री के रूप में स्टायरोफोम वाले बामक्रीट पैनल में सबसे कम संपीड़न शक्ति होती है, जबकि तार की जाली से लिपटे बांस की जाली और मुख्य सामग्री के रूप में फाइबर प्रबलित एससीएम वाले बामक्रेट पैनल में उच्चतम संपीड़न शक्ति होती है। इस प्रकार, कोर सामग्री का Bamcrete पैनलों के थर्मल गुणों पर महत्वपूर्ण प्रभाव पड़ता है।

आग की स्थिति के दौरान 600°C तक ऊंचे तापमान पर केंद्रित भार के तहत Bamcrete पैनल का परीक्षण किया गया। सबसे अधिक भार वहन करने की क्षमता या कतरनी ताकत बैमक्रीट पैनल (नंबर 9) में थी, जिसमें बांस की जाली को तार की जाली से लपेटा गया था और मुख्य सामग्री के रूप में फाइबर प्रबलित एससीएम था, जबकि पैनल (नंबर 2) में सीमेंट घोल के साथ लेपित बांस की जाली थी। और मुख्य सामग्री के रूप में स्टायरोफोम शीट की परिवेश के तापमान के साथ-साथ 600°C के ऊंचे तापमान पर सबसे कम ताकत होती है। परिवेश और 600°C पर पैनल द्वारा लिया गया उच्चतम भार क्रमशः 113 kN

और 82 kN था। Bamcrete पैनलों के दृश्य निरीक्षण से पता चला कि 400°C पर परीक्षण के दौरान स्टायरोफोम शीट जल गई थी। 500°C के तापमान तक परीक्षण के दौरान किसी भी पैनल में कोई खराबी नहीं आई और बुनी हुई बांस की जाली भी नहीं जली। हालाँकि, 600°C के तापमान पर परीक्षण के दौरान, पैनल नंबर को छोड़कर अधिकांश पैनलों में बुना हुआ बांस का जाल जल गया था। 9. ऊंचे तापमान पर ताकत के नुकसान को नियंत्रित करने में बैमक्रीट पैनलों पर गर्मी प्रतिरोधी पेंट (एचआरपी) की कोटिंग बहुत महत्वपूर्ण पाई गई। इस प्रकार, एचआरपी लेपित बैमक्रीट पैनल अग्निरोधी इमारत के लिए एक टिकाऊ और कुशल सामग्री हैं। वर्तमान निष्कर्ष बांस-आधारित प्री-कास्ट संरचनाओं को लोकप्रिय बनाने में मदद करेंगे और बांस की मांग में वृद्धि करेंगे, कृषि उत्पादन में अधिक विविधता प्रदान करेंगे और स्थानीय अर्थव्यवस्था को प्रोत्साहित करेंगे।

संकेतशब्द:

बांस, बैमक्रीट पैनल, सेल्फ-कॉम्पैक्टिंग मोर्टार, फ्लाई ऐश, ग्लास वूल फाइबर, रेक्रॉन फाइबर, टिकाऊपन, ऊंचा तापमान, यांत्रिक गुण, थर्मल चालकता और रिबाउंड हैमर, हीट प्रतिरोधी पेंट-कोटिंग।

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Notations

Abbreviations

ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
BRC	Bamboo Reinforced Concrete
CA	Coarse aggregate
CS	Compressive Strength
DSC	Differential scanning calorimetry
FA	Fly ash
FS	Flexural Strength
FTIR	Fourier Transform Infrared
GGBS	Ground granulated blast furnace slag
GWF	Glass Wool Fibres
HRP	Heat Resistant Paint
IS	Indian Standard
OPC	Ordinary Portland cement
PCC	Plain cement concrete
PCE	Polycarboxylate ether
PP	Polypropylene
PPC	Portland pozzolana cement (fly ash-based)
RCC	Reinforced cement concrete
RCPT	Rapid Chloride Penetration Test
SCC	Self-compacting concrete
SCM	Self-compacting Mortar
SEM	Scanning electron microscope
Strength	Compressive strength of concrete at a particular age
TGA	Thermogravimetric analysis
SSD	Surface saturated dry

Symbols and Notations

Rs.	Indian Rupee
b	Effective binder, that is, $c+kf$ (kg/m^3)
c	Ordinary Portland cement (kg/m^3) unless otherwise stated
C_7	Compressive strength of concrete of 150 mm cubes at 7 days (MPa)
C_{28}	Compressive strength of concrete of 150 mm cubes at 28 days (MPa)
cm	Cementitious material, that is, the sum of cement and fly ash (kg/m^3)
f	Fly ash (kg/m^3)
$f\%$	Fly ash percentage (%), that is, $f/(c+f)$
k_{28}	Efficiency factor of fly ash at 28 days
k_7	Efficiency factor of fly ash at 7 days
k-value	Efficiency factor of fly ash
p	Powder content = the sum of cement and fly ash and Marble powder(kg/m^3)
s	Natural sand or fine aggregate (kg/m^3)
s/a	Sand to total aggregate ratio
USD	USA Dollar
w	Water (kg/m^3)
$\frac{w}{b} = \frac{w+\alpha F}{c+kf}$	Effective Water to cement ratio
min	Minute (time)