CGAs-BASED LIGHT-WEIGHT CONCRETE

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CGAs-BASED LIGHT-WEIGHT CONCRETE

by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

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Dedicated to my parents

CERTIFICATE

This is to certify that the thesis entitled **"CGAs-based light-weight concrete"** being submitted by **Arunima Shukla** to the Department of Chemical Engineering, Indian Institute of Technology, New Delhi, for the fulfilment of the requirements for the award of Doctor of Philosophy in Chemical Engineering, is a record of bonafide work carried out by her. She has worked under my guidance and supervision and has fulfilled the requirements, which to my knowledge, has reached the requisite standard for the submission of the thesis.

The research report and results presented 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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ABSTRACT

Autoclaved aerated concrete (AAC) has been a worldwide leading sector in the aerated concrete industry for decades and used as a non-load bearing building material. Today, as the demand and requirements of green buildings are increasing, there are more than 3000 manufacturing facilities producing aerated concrete in many countries, and under all kinds of climatic conditions. International green policies are also raising demand for more efficient and economical processes for the production of aerated concrete.

An environment-friendly and a cheaper technology to manufacture an alternative to the present-day commercially available AAC has been found in the present study of aerated concrete. High energy efficiency is one of the defining characteristics of aerated concrete made by the new route of colloidal gas aphrons (CGAs). CGAs are microbubbles of air encapsulated by multi-layers of surfactant molecules and hydrogen-bonded water. Properties of CGAs and the uniformity of sizes of micro-bubbles allow aeration of cement mortar and solid-wastes inclusion with gain in physical, chemical, and mechanical properties.

CGAs have been studied extensively, it was observed that recycling of CGAs dispersion will result in higher air hold-up in the range of 0.75 to 0.80 for anionic surfactant (SLS). Moreover, CGAs generated with SLS were much more stable than CGAs obtained from cationic (CTAB) and non-ionic surfactants (Tween 80).The size range of 1-800 μm and the specific areas of 48000-60 cm^2/cm^3 for air hold-up of 0.80 were observed. The measured size distribution could be fitted with lognormal distribution with a correlation coefficient of about 0.99.

Moreover, the CGAs generation kinetic model was studied and 1^{st} order kinetic equation correlated the data very well.

A new simple model for the generation mechanism of CGAs was developed and verified by the experimental results. This model can predict the air hold-up of CGAs.

CGAs have been used as an aerating agent to produce aerated concrete: These have been termed as Light Weight Concretes (LWCs). LWCs with different porosity (in the range of 0.62 to 0.78) could be prepared. LWCs were made, by utilizing two different types of fly ash, and achieved sample densities were in the range of 392 -1301 kg/m^3. Effect of curing on the properties of concrete was observed. Curing of LWCs by three different methods viz. autoclaving, warm water curing, and 28 days water curing were carried out. It was observed that autoclaving resulted in the highest strength as compared to the other curing methods.

Properties such as density, compressive strength, drying shrinkage, water absorption, of concrete samples have been measured and that all meets the Indian standards (IS 2185).
Another important problem addressed in the present study is that of solid-waste utilization, the waste materials were from automated AAC industry. We reincorporated the three different sizes of crushed autoclaved aerated concrete (CAAC) waste up to 25% of the total solids in new aerated concrete blocks.
This method of inclusion of the industrial solid wastes in aerated concrete may contribute to credits in 'Leadership in Energy and Environmental Design', or other rating systems for the design, construction, operation, and maintenance of green buildings, besides achieving a zero-waste manufacturing process for the aerated concrete products.
Steel wires could also be incorporated in the production of LWCs. These result in the electrical conductivity in the range of 1.40×10^{-4} to 2.00×10^{-3} $(\Omega.cm)^{-1}$, and density in the range of 700 kg/m^3-800 kg/m^3. The addition of these wires along with CGAs has surprisingly increased the compressive strength (6.07-8.33 MPa) and tensile strength (0.55-1.48 MPa), while the drying shrinkage reduced further, to the range of 0.011-0.016%. All the properties of aerated concrete blocks were measured, and are in accordance with the Indian Standard, IS 2185 part 4. Aerated concrete along with electrical conductivity is a novel idea. It will not only help to generate the heat but also keep the area warmer for a longer time. These blocks have an application in the cold terrains/countries, de-icing of roads/airports, and electrical grounding.
Ferret's and Balshin's models were used to predict the compressive strength of the aerated concrete blocks.
Therefore, CGAs route for manufacturing aerated concrete can be a path-breaking large-scale operation worldwide because other than aluminum powder coupled with autoclaving there is no other aeration method used presently for the large-scale production.

Keywords: Aerated concrete; CGAs; Electrically conductive concrete; CGAs generation kinetics; CGAs generation mechanism.

सार

ऑटोक्लेवड वातित कंक्रीट (AAC) दशकों से वातित कंक्रीट उद्योग में दुनिया भर में अग्रणी क्षेत्र रहा है और इसका उपयोग गैर-लोड निर्माण सामग्री के रूप में किया जाता है। आज, जैसा कि हरी इमारतों की मांग और आवश्यकताएं बढ़ रही हैं, कई देशों में और सभी प्रकार की जलवायु परिस्थितियों में, वातित कंक्रीट का उत्पादन करने वाली 3000 से अधिक विनिर्माण सुविधाएं हैं। अंतर्राष्ट्रीय ग्रीन नीतियां वातित कंक्रीट के उत्पादन के लिए अधिक कुशल और किफायती प्रक्रियाओं की मांग भी उठा रही हैं।

वर्तमान में व्यावसायिक रूप से उपलब्ध AAC के विकल्पस्वरूप एक पर्यावरण-अनुकूल और एक सस्ती तकनीक का निर्माण किया गया है जो वातित कंक्रीट के वर्तमान अध्ययन में पाया गया है। उच्च ऊर्जा दक्षता कोलाइडल गैस एफ्रॉन (CGAs) के नए मार्ग द्वारा बनाई गई वातित कंक्रीट की परिभाषित विशेषताओं में से एक है। CGAs सर्फेक्टेंट अणुओं और हाइड्रोजन-बंधुआ पानी की बहु-परतों द्वारा घिरे हवा के सूक्ष्म बुलबुले हैं। CGA के गुण और सूक्ष्म बुलबुले के आकार की एकरूपता सीमेंट मोर्टार और कंक्रीट अपशिष्टों के वातन को भौतिक, रासायनिक और यांत्रिक गुणों में लाभ के साथ शामिल करने की अनुमति देती है। सीजीए का बड़े पैमाने पर अध्ययन किया गया है, यह देखा गया है कि सीजीए डिस्परजन के पुनर्चक्रण के परिणामस्वरूप एनियनिक सर्फेक्टेंट (SLS) के लिए 0.75 से 0.80 की सीमा में उच्च वायु होल्ड-अप होगा।

इसके अलावा, SLS के साथ उत्पन्न CGAs कैटायनिक (CTAB) और गैर-आयनिक सर्फेक्टेंट (Tween 80) से प्राप्त CGAs की तुलना में बहुत अधिक स्थिर थे। 1-800 μm की आकार सीमा और 0.80 के वायु होल्ड-अप के लिए 48000-60 cm^2/cm^3 के विशिष्ट क्षेत्र का अवलोकन किया गया। मापा आकार वितरण को लगभग 0.99 के सहसंबंध गुणांक के साथ लॉग नार्मल डिस्ट्रीब्यूशन के साथ फिट किया जा सकता है। इसके अलावा, CGAs उत्पादन गतिज मॉडल का अध्ययन किया गया था और पहली क्रम गतिज समीकरण ने डेटा को बहुत अच्छी तरह से सहसंबद्ध किया।

CGA के उत्पादन क्रियाविधि के लिए एक नया सरल मॉडल प्रयोगात्मक परिणामों द्वारा विकसित और सत्यापित किया गया था। यह मॉडल CGA के वायु होल्ड-अप की पूर्व-सूचना दे सकता है।

सीजीए का उपयोग वातित कंक्रीट के उत्पादन के लिए एक एरेटिंग एजेंट के रूप में किया गया है: इन्हें हल्के कंक्रीट (LWCs) कहा गया है। विभिन्न सरंध्रता वाले LWCs (0.62 से 0.78 की सीमा में) तैयार किए जा सकते हैं। LWCs दो अलग-अलग प्रकार की फ्लाई ऐश का उपयोग करके बनाया गया था, और प्राप्त नमूने घनत्व 392 -1301 kg/m^3 की सीमा में थे। कंक्रीट के गुणों पर क्योरिंग का प्रभाव देखा गया। तीन अलग-अलग तरीकों से LWCs की क्योरिंग की गई जैसे, आटोक्लेविंग, गर्म पानी से क्योरिंग, और 28 दिनों के पानी की क्योरिंग। यह देखा गया कि अन्य क्योरिंग के तरीकों की तुलना में ऑटोक्लेविंग में सबसे अधिक ताकत थी। घनत्व, संपीड़ित

शक्ति, सुखाने संकोचन, जल अवशोषण, जैसे कंक्रीट के नमूनों के गुणों को मापा गया है और यह सभी भारतीय मानकों (IS 2185) से मिलता है। वर्तमान अध्ययन में संबोधित एक और महत्वपूर्ण समस्या कंक्रीट-अपशिष्ट उपयोग की है, अपशिष्ट पदार्थ स्वचालित AAC उद्योग से थे। हमने नए कंक्रीट ब्लॉकों में कुल कंक्रीट पदार्थों के 25% तक पिसे हुए ऑटोक्लेवड वातित कंक्रीट (CAAC) के तीन अलग-अलग आकारों को फिर से शामिल किया।

वातित कंक्रीट में औद्योगिक कंक्रीट अपशिष्टों को शामिल करने की यह विधि शून्य ऊर्जा प्राप्त करने के अलावा, हरे रंग की इमारतों के डिजाइन, निर्माण, संचालन और रखरखाव के लिए 'लीडरशिप इन एनर्जी एंड एनवायर्नमेंटल डिज़ाइन' में क्रेडिट के लिए योगदान दे सकती है।

LWCs के उत्पादन में स्टील के तारों को भी शामिल किया जा सकता है। इनका परिणाम 1.40×10^{-4} से 2.00×10^{-3} $(\Omega.\text{cm})^{-1}$ तक की विद्युत चालकता में होता है, और घनत्व 700 kg/m^3-800 kg/m^3 की सीमा में होता है। सीजीए के साथ इन तारों को शामिल करने से आश्चर्यजनक रूप से संपीड़ित शक्ति (6.07-8.33 MPa) और तन्य शक्ति (0.55-1.48 MPa) में वृद्धि की है, जबकि सुखाने संकोचन, 0.011.01.016% की सीमा तक कम हो गया। वातित कंक्रीट ब्लॉकों के सभी गुणों को मापा गया था, और वे भारतीय मानक के अनुसार हैं, IS 2185 भाग 4. वातित कंक्रीट के साथ-साथ विद्युत चालकता एक नव विचार है। यह न केवल गर्मी उत्पन्न करने में मदद करेगा बल्कि क्षेत्र को लंबे समय तक गर्म भी रखेगा। इन ब्लॉकों का ठंडे इलाकों / देशों, सड़कों / हवाई अड्डों की डी-आइसिंग, और विद्युत ग्राउंडिंग में एक आवेदन है।

फेरेट और बालशिन के मॉडल का उपयोग वातित कंक्रीट ब्लॉकों की संपीड़ित शक्ति की पूर्व-सूचना देने के लिए किया गया था।

इसलिए, वातित कंक्रीट के निर्माण के लिए सीजीए मार्ग दुनिया भर में एक अग्रणी बड़े पैमाने पर संचालन हो सकता है, क्योंकि एल्यूमीनियम पाउडर के साथ युग्मित ऑटोक्लेविंग के अलावा बड़े पैमाने पर उत्पादन के लिए वर्तमान में उपयोग की जाने वाली कोई अन्य वातन विधि नहीं है।

कीवर्डस: वातित कंक्रीट; CGAS; विद्युत प्रवाहकीय कंक्रीट; CGAs उत्पादन गतिज मॉडल; CGAs उत्पादन क्रियाविधि।

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LIST OF ABBREVIATIONS

S. No.	Abbreviation	Title
1	CGA	Colloidal gas aphron
2	AAC	Autoclaved aerated concrete
3	AACW	Autoclaved aerated concrete waste
4	CAAC	Crushed autoclaved aerated concrete
5	POFA	Palm oil fuel ash
6	OPC	Ordinary Portland cement
7	CMC	Critical micelle concentration
8	LWC	Light weight concrete
9	GGBFS	Ground granulated blast furnace slag
10	w/s	Water/Solid
11	a/c	Air/Cement
12	SLS	Sodium lauryl sulfate
13	CTAB	Cetyl trimethyl ammonium bromide
14	SEM	Scanning electron microscope
15	XRD	X-ray diffraction

LIST OF NOTATIONS

A	Species in the aphrons (air here)
A_s	Samples cross-sectional area, [cm^2]
A_T	Total surface area per unit volume of the suspension, [$\mu m^2/\mu m^3$]
d_a	Mean aphron size, [μm]
d_c	Fresh density, [kg/m^3]
D_A	Diffusivity of A, [m^2 / s]
g	Gel-space ratio, dimensionless
K	Intrinsic strength of the gel, [MPa]
k	first-order rate constant, [s^{-1}]
k_a	Area shape factor, dimensionless
k_v	Volume shape factor, dimensionless
k_s	Water/Solid ratio by weight, dimensionless
K_s	Constant, dimensionless
L	Mean size in a bin is equal to dimension in distribution function, [μm]
L_s	Sample thickness, [cm]
L’	Geometric mean size in lognormal distribution, [μm]
m_0	Zero moment, [No of bubbles/μm^3]
m_1	First moment, [$\mu m/\mu m^3$]
m_2	Second moment, [$\mu m^2/\mu m^3$]
m_3	Third moment, [$\mu m^3/\mu m^3$]
n	Constant
n(L)	Non-normalized distribution function, μm^{-4}
P	Permeability, [(kmol m) / (m^2 s Pa)]
P_{cr}	Critical porosity for zero strength
Q_{cga}	volumetric flow rate of CGAs, [mL/s]
S	Strength, [MPa]
S_o	Strength at zero porosity, [MPa]
S_A	Solubility coefficient or Henry’s law constant, [kmol / (m^3 Pa)]
S_v	Filler-cement ratio by volume, [m^3]
S_w	Filler-cement ratio by weight, dimensionless
t	Time, [s]

V_l	Initial volume of liquid, [mL]
V_{cga}	volume of CGAs at time t, [mL]
$V_{cga(f)}$	Final volume of CGAs, [mL]
$V_{cga\ (i)}$	Initial volume of the aqueous solution, [mL]
V_c	Volume of cement, [m^3]
V_{fl}	Volume of fillers per m^3 of cement, dimensionless
α	Degree of hydration
σ'	Width parameter in lognormal distribution equal to geometric standard deviation, [μm]
φ	Air hold-up of CGAs
ε	Electrical resistivity, c
∂	Electrical conductivity, $(\Omega\ cm)^{-1}$
ε_{go}	Gas hold-up at time t_0, dimensionless
ε_g	Gas hold-up at time t, dimensionless
ε_{gf}	Gas hold-up at time $t_{0.99}$, dimensionless