

Comparative study of engineering aspects of fire brick and borosilicate glass block linings in design of reinforced concrete chimneys

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Abstract

Tall chimney construction has been possible with building technologies and also with good understanding of loads acting on them to determine its structural behaviour. The experience gained in the chimney construction and design over the years the now a-day challenge is to prevent the chimney shell and lining deterioration due to penetration of flue gases through cracks in the air space. Considering borosilicate blocks as a lining material, Chimneys have been designed. It has also been reported about repairing the deteriorated chimney by removing the conventional fire bricks and applying borosilicate block on the chimney shell. The engineering properties of both the lining materials are compared in this paper. Also, the analytical study has been done on 12 hypothetical chimneys with the temperature varying at 150°C and 200°C and 200m, 150m and 100m height to gauge the effectiveness borosilicate glass blocks in terms of temperature gradient, forces induced and material cost. The study shows that borosilicate block can be a suitable replacement of conventional fire bricks, used as lining for reinforced concrete chimneys, in terms of its application and its engineering properties that govern structural parameters.

Keywords: *RCC chimney, Borosilicate glass block lining, Acid proof fire brick lining*

1. Introduction

A chimney is a structure from which flue gases or smoke is discharged at a high elevation into the atmosphere. It helps in the reduction in the pollutant levels in the atmosphere. Such as, Power Plants, Process Plant (Cement, Refineries, Chemical, Fertilizer, etc.) Chimney from an important part of industrial structures. A 122 m (400 ft) high chimney was considered to be very tall in the early 1960s, and many chimneys in the range of 220 m height have been built in our country nowadays. Several chimneys in the range of 380 m (1250 ft) already exist in the USA, and this trend toward constructing taller chimneys will continue. Construction and design of such tall chimneys has been possible with the better understanding of the structural behaviour and loads acting on them, above all with the utilization of modern techniques such as slip-form, equipment, and construction plant. For resist wind load and other forces acting on chimney, as

a self-standing structure the reinforced concrete has been the most favoured material for chimney construction. With the experience gained in the chimney design and construction over the years, the country has been able to meet the present-day challenges of deterioration of chimney material due to temperature stress and acid attack on RCC shell. It over-came by brick liners [1, 2]. Based on that, the present study focused on considering economic and efficiency criteria of design of RCC chimney with borosilicate and brick linings. The study has been divided into two parts. First part is covering comparison of engineering properties and second part is covering the comparison of structural results considering the two different lining materials.

1.1 Comparison of Physical Properties

Table 1: Property of borosilicate glass block [3, 4]

Description	PROPERTIES OF BOROSILICATE GLASS BLOCK	PROPERTIES OF FIRE-RESISTANT BRICK	Observations
Composition	Borosilicate glass, inorganic	ACID PROOF FIRE BRICK	Resistant to corrosive flue gas environments.
Service Temperature Limit	390°F/200°C. Maximum service temperature values for foamed glass compositions are a function of resistance to deformation (creep) under load, thermal shock resistance.	250 °C maximum service Temperature	Service Temperature is more in Fire resistant brick
Thermal Conductivity (ASTM C-117, C-518)	100°F (38°C) mean (0.087 W / m•K)	(1.25 W / m•K)	Borosilicate glass block is

	200°F (93°C) mean (0.098 W / m•K)		excellent thermal insulation, energy savings, eliminates external insulation
	300°F (149°C) mean (0.11 W / m•K)		
Density (ASTM C-303)	192 kg/m ³	2000 kg/m ³	Borosilicate glass block density is Around 1/10 th of fire-resistant brick
Modulus of elasticity	1240 MPa	2133 Mpa	
Coefficient of linear thermal expansion	5.5 x 10-6/°C	10 x 10-6/°C	Fire resistant brick has High thermal expansion and less resists thermal shock and

			upset temperatures comparative to borosilicate glass block
Capillarity	None	11.6 % after a minute	Virtually zero permeability, capillarity, and absorption, closed celled structure for borosilicate glass block
Absorption of moisture, (ASTM C-240)	0.2 (surface wetting only)	12.25%	
Water Vapor Permeability	0 m / s	3.35×10^{-12} m/s	
Shelf Life	Indefinite	20 Years	

2. Design Consideration and Comparison of Analytical Results

2.1 Design Consideration for RCC Chimney

RCC Chimney is a tall cantilever and is designed as per IS: 4998-2015. Tall RC chimney circular cross section, apart from dead loads, are wind sensitive structures that shall be designed to resist both the along and across wind effects. Moreover, by the circumference pressure distribution hollow circular cross section shall be designed to resist loads caused. The effect of dynamic fluctuation is taken into account as static equivalent loads through the concept of gust response factor for the computation of along loads. The effect of temperature gradients is to produce compressive stresses on the inner side of shell and tensile stresses on the outer side of shell, and they act both in horizontal and vertical directions.[5]

2.2 Case Study Specifications

12 chimneys were studied with varying temperatures and heights. Chimneys were designed with conventional brick lining and borosilicate linings and comparison was done in terms of forces and material cost.

Table 2: RCC chimney models for comparison

Specifications of the cases to study		
Height of RCC Chimney	Inner temperature of RCC chimney	Type of lining
100 m	150° C, 200° C	Conventional brick lining RCC chimney & borosilicate glass block lining RCC chimney
150 m		
200 m		

H100T200B means height of the chimney is 100m, it is subjected to 200° C temperature and lining material is brick. G stands for borosilicate glass block lining.

H used for height of RCC chimney in m.

T used for inner temperature of RCC chimney in degree Celsius.

B used for conventional brick lining system of RCC chimney.

G used for borosilicate glass block lining system of RCC chimney.

2.3 Analytical Result of RCC Chimney in tabular form

Tables 5 shows the analytical results for RCC chimney with 100m Height and varying temperatures with conventional brick and borosilicate block lining.

Table 3 Analytical result of 100 m RCC chimney.

Lining system	Brick lining		Borosilicate glass block lining	
	H100T150B	H100T200B	H100T150G	H100T200G
Chimney	H100T150B	H100T200B	H100T150G	H100T200G
Bottom outer dia (m)	6.11 m	6.21 m	5.66 m	5.71 m
Top outer dia.(m)	4.46 m	4.46 m	3.91 m	3.91 m
Thickness of shell	0.40 m	0.40 m	0.40 m	0.40 m
P (kN)	17640	17773	14203	14255
M (kN.m)	78898	78563	72763	72618
A (m ²)	7.18	7.30	6.61	6.67
Z (m ³)	9.62	9.97	8.12	8.28
P/A + M/Z (N/ mm ²)	11	10	11	11
P/A-M/Z (N/ mm ²)	-6	-5	-7	-7
Frequency (Hz)	0.41	0.41	0.37	0.37
T _x (° C)at bottom of RCC chimney	31.43	43	16.71	22.75
Reduced f _{ck} (N/ mm ²)	31.9	30.79	33.36	32.7

Reduced f_y (N/ mm ²)	460	445	479	471
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Tables 6 shows the analytical results for RCC chimney with 150m Height and varying temperatures with conventional brick and borosilicate block lining.

Table 4: Analytical result of 150 m RCC chimney.

Lining system	Brick lining		Borosilicate glass block lining	
	H150T150B	H150T200B	H150T150G	H150T200G
Chimney				
Bottom outer dia (m)	9.33 m	9.49 m	8.62 m	8.70 m
Top outer dia.(m)	4.46 m	4.46 m	3.91 m	3.91 m
Thickness of shell	0.40 m	0.40 m	0.40 m	0.40 m
P (kN)	32683	33002	26549	26678
M (kN.m)	187377	186545	174434	174087
A (m ²)	11.22	11.42	10.33	10.43
Z (m ³)	24.03	24.91	20.29	20.70
P/A + M/Z (N/ mm ²)	11	10	11	11
P/A-M/Z (N/ mm ²)	-5	-5	-6	-6
Frequency (Hz)	0.29	0.29	0.27	0.27
Tx (° C)at bottom of RCC chimney	40.41	55.77	18.5	25.24

Reduced f_{ck} (N/ mm ²)	31.05	30	33.192	32.53
Reduced f_y (N/ mm ²)	449	429	476	468

Tables 7 shows the analytical results for RCC chimney with 200m Height and varying temperatures with conventional brick and borosilicate block lining.

Table 5: Analytical result of 200 m RCC chimney.

Lining system	Brick lining		Borosilicate glass block lining	
	H200T150B	H200T200B	H200T150G	H200T200G
Chimney				
Bottom outer dia (m)	12.74 m	12.98 m	11.76 m	11.86 m
Top outer dia.(m)	4.46 m	4.46 m	3.91 m	3.91 m
Thickness of shell	0.40 m	0.40 m	0.40 m	0.40 m
P (kN)	52973	53600	43246	43471
M (kN.m)	341932	340187	321431	320771
A (m ²)	15.51	15.81	14.28	14.40
Z (m ³)	46.39	48.23	39.21	39.92
P/A + M/Z (N/ mm ²)	11	10	11	11
P/A-M/Z (N/ mm ²)	-4	-4	-5	-5
Frequency (Hz)	0.22	0.22	0.21	0.21

Tx (° C)at bottom of RCC chimney Tx (° C)	42.29	58.37	18.86	25.73
Reduced f_{ck} (N/ mm ²)	30.86	29.29	33.156	32.48
Reduced f_y (N/ mm ²)	446	426	476	467

- Following are the observation pertaining two difference parameters consider while designing the above mention chimney or while designing the chimney taken for the case study.
 - The bottom outer diameter of chimneys with borosilicate lining reduces to about 7-9% as compared to those with brick lining.
 - The top outer diameter of chimneys with borosilicate lining reduces to about 14% as compared to those with brick lining (For same inside clear dimension)
 - The total weight of RCC chimneys with borosilicate lining reduces to about 24-25% as compared to those with brick lining.
 - The bottom moment of RCC chimneys with borosilicate lining reduces to about 8-9 % as compared to those with brick lining.
 - The frequency of RCC chimneys with borosilicate lining is about 7-10% lower as compared to those with brick lining. (due to large bottom diameter of brick lining of RCC chimney)
 - The temperature gradient through the RC shell of chimneys with borosilicate lining reduces to about 40-50 % as compared to those with brick lining.
 - The reduction in characteristic strength of concrete and yield strength of reinforcement are less with borosilicate liner by about 2-6 %

2.5 Comparison of material consumption

Tables 12 to 14 give the tabulated form of material consumption and cost associated with it as used in practice. In present study, only concrete shell is considered for cost comparison. Following are the rates considered:

Cost of Concrete: 6000 Rs. / m³ (RMC M35 grade concrete),

Cost of Reinforcement: 60000 Rs. Per tonne.

Cost of Borosilicate glass block: 23100 Rs. / m² (as given by the supplier)

Cost of Acid proof fire bricks: 22000 Rs. / m²

Cost of form-work: 600 Rs. / m²

Table 6: Quantity and cost of material of RCC chimney.

	Quantity	Cost(Rs.)	(%)		Quantity	Cost(Rs.)	(%)
Chimney	H100T150B			Chimney	H100T150G		
Concrete(m ³)	635	38,10,000	9.39	Concrete(m ³)	522	31,32,000	8.69
Lining quantity(m ²)	1422	3,12,84,000	77.12	Lining quantity(m ²)	1197	2,76,50,700	76.75
Reinforcement (Tonne)	61.71	37,02,611	9.13	Reinforcement (Tonne)	61.26	36,75,655	10.20
Formwork (m ²)	2950	17,70,000	4.36	Formwork (m ²)	2611	15,66,600	4.35
Total cost of RCC chimney		4,05,66,611		Total cost of RCC chimney		3,61,62,475	
Chimney	H100T200B			Chimney	H100T200G		
Concrete(m ³)	640	38,40,000	9.39	Concrete(m ³)	524	31,44,000	8.69
Lining quantity(m ²)	1433	3,15,26,000	77.06	Lining quantity(m ²)	1202	2,77,66,200	76.78
Reinforcement (Tonne)	62.68	37,60,951	9.19	Reinforcement (Tonne)	61.32	36,79,675	10.18
Formwork (m ²)	2972	17,83,200	4.36	Formwork (m ²)	2621	15,72,600	4.35
Total cost of RCC chimney		4,09,10,151		Total cost of RCC chimney		3,63,00,273	

Material consumption and cost of materials for chimneys with 150m height

Table 7: Quantity and cost of material of RCC chimney

	Quantity	Cost(Rs.)	(%)		Quantity	Cost(Rs.)	(%)
Chimney	H150T150B			Chimney	H150T150G		
Concrete(m ³)	1177	70,62,000	9.06	Concrete(m ³)	978	58,68,000	8.30
Lining quantity(m ²)	2660	5,85,20,000	75.12	Lining quantity(m ²)	2287	5,28,29,700	74.68
Reinforcement (Tonne)	150.71	90,42,844	11.61	Reinforcement (Tonne)	151.8	91,08,444	12.88
Formwork (m ²)	5468	32,80,800	4.21	Formwork (m ²)	4891	29,34,600	4.15
Total cost of RCC chimney		7,79,05,644		Total cost of RCC chimney		7,07,40,744	
Chimney	H150T200B			Chimney	H150T200G		
Concrete(m ³)	1188	71,28,000	9.06	Concrete(m ³)	983	58,98,000	8.30
Lining quantity(m ²)	2686	5,90,92,000	75.10	Lining quantity(m ²)	2299	5,31,06,900	74.70
Reinforcement (Tonne)	152.54	91,52,687	11.63	Reinforcement (Tonne)	152.38	91,43,310	12.86
Formwork (m ²)	5521	33,12,600	4.21	Formwork (m ²)	4916	29,49,600	4.15
Total cost of RCC chimney		7,86,85,287		Total cost of RCC chimney		7,10,97,810	

Material consumption and cost of materials for chimneys with 200m height

Table 8: Quantity and cost of material of RCC chimney

	Quantity	Cost(Rs.)	(%)		Quantity	Cost(Rs.)	(%)
Chimney	H200T150B			Chimney	H200T150G		
Concrete(m ³)	1886	1,13,16,000	8.67	Concrete(m ³)	1575	94,50,000	7.91
Lining quantity(m ²)	4289	9,43,58,000	72.32	Lining quantity(m ²)	3733	8,62,32,300	72.15
Reinforcement (Tonne)	325.57	1,95,34,293	14.97	Reinforcement (Tonne)	318.6	1,91,16,227	15.99
Formwork (m ²)	8764	52,58,400	4.03	Formwork (m ²)	7876	47,25,600	3.95
Total cost of RCC chimney		13,04,66,693		Total cost of RCC chimney		11,95,24,127	
Chimney	H200T200B			Chimney	H200T200G		
Concrete(m ³)	1909	1,14,54,000	8.67	Concrete(m ³)	1584	95,04,000	7.91
Lining quantity(m ²)	4341	9,55,02,000	72.32	Lining quantity(m ²)	3755	8,67,40,500	72.20
Reinforcement (Tonne)	329.51	1,97,71,026	14.97	Reinforcement (Tonne)	318.92	1,91,35,386	15.93
Formwork (m ²)	8868	53,20,800	4.03	Formwork (m ²)	7921	47,52,600	3.96
Total cost of RCC chimney		13,20,47,826		Total cost of RCC chimney		12,01,32,486	

3. Conclusion

The RCC Chimney with borosilicate glass block liner, design is a reliable, quicker, and cost-effective way of building a chimney for wet flue gas emission. By keeping stresses at the base same, the outer bottom diameter of RCC chimney with borosilicate glass block lining reduces by 6-8 % as compared to that of chimney with conventional brick lining. Overall dead load of the structure is also reduced by 20-23% in borosilicate glass block lined chimney which can result in cheaper foundations. The consumption and cost of the lining for RCC chimney with borosilicate glass block is 8-10 % less as compared to those for chimneys lined with conventional fire bricks. From the above study, it can be concluded that cost of concrete

is about 9-9.5%, Reinforcement cost is 9-15 %, formwork cost is about 4-4.5 % and lining cost is about 75-77 % of the total cost of brick lined chimney. Whereas cost of concrete is about 8-9%, Reinforcement cost is 10-16%, formwork cost is 3.9-4.5 % and lining cost is about 72-77% of the total cost of Borosilicate block lined chimney. Here reinforcement cost hardly changes, major cost difference is due to reduced concrete volume and application of borosilicate blocks that are comparatively cheaper than fire resistant bricks. From the above calculations it can be concluded that cost of borosilicate block lined chimney is about 10-12% less as compared to brick lined chimney.

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