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DEVELOPMENT OF LIGHTWEIGHT CONCRETE INFILLED SANDWICH WALL PANEL

K. N. Lakshmikandhan*, K. Sivasubramanian, J. Prabakar and B. S. Harshavardhan
CSIR-SERC, Chennai, India

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ABSTRACT

Masonry structures are popularly used in the construction for the several thousand years. The masonry walls have showed inferior performance during any uncertain loads. Lightweight wall panels are the better alternative for the masonry structures. Lightweight concrete is developed by mixing the 3 mm diameter EPS (Expanded Polystyrene) beads and a flowable concrete. The sandwich wall panel is developed using the lightweight concrete with a density of about 920 kg/m^3. Cubes and cylinders are tested and developed a material model for the lightweight concrete. A wall panel of size 1.25 m * 1.25 m * 150 mm is cast with a lightweight concrete inner core and tested for in-plane compression loading. A nonlinear finite element analysis is carried out with material nonlinearities and compared with experimental results. The results are found comparable and it confirms the material model developed. The present study showed that the lightweight concrete sandwiched with ferrocement skin is well suitable for the wall construction.

Keywords: Sandwich; wall panel; lightweight concrete; ferrocement; FEA; nonlinearity.

1. INTRODUCTION

Evolution of the development of construction activities around the world, the demand for construction materials is increasing exponentially. Available resources of natural aggregates are at a considerable distance away from the point of use, in such case the cost of transporting is a disadvantage. This trend will have a greater influence on the economic system of developing countries. Continued extraction of natural aggregate is accompanied by serious environmental problems. Furthermore, the wall constructed with conventional masonry system contributes higher dead weight to the structure. To carry the higher structural dead load requires heavier sections of beams, columns and foundation. The reduction in the weight of wall will significantly reduce the dead weight of structure which results in overall reduction in sizes of structural components. Furthermore, the improved

*E-mail address of the corresponding author: kandhan@serc.res.in (K. N. Lakshmikandhan)

technologies are necessary to manage the shortfall in the availability of natural aggregate materials. With these reasons, there is a need for the alternative system to fulfill the construction demand without compromising strength, affordability and environmental friendly. The concrete sandwich panels are such system, which is more suitable for wall construction. The concrete sandwich panel consists of lightweight expanded polystyrene plate with skin concrete on both sides. EPS (Expanded Polystyrene) panels are factory made and it consists of EPS plate with interconnected steel weld meshes on both sides. The steel meshes are interconnected with the shear connector by fusion welding. The process of welding escalates the cost of EPS panel and the cost escalation becomes a constraint for its effective usage. The major portions of wealth are spent for the construction of these structures and it becomes a key factor of social development. Researchers are very much interested in developing technologies for improved strength, safety and economy.

The masonry walls are very popularly used for building construction for several hundreds of years, but it exhibits inferior structural performance during any uncertain loads [1], [2]. The performance of unreinforced masonry walls can be improved by introducing steel reinforcement [3]. The design dead weight of reinforced masonry walls is increased. Many attempts are also made to utilize the ferrocement for infilled wall system, which has higher strength, better crack resistance, improved ductility, higher strength to weight ratio and good energy absorption characteristics [4- 10]. The Construction of ferrocement wall panel requires skilled persons and moreover, it has lesser sound and heat proof. The deficiencies can be overcome with the sandwich wall panel. The sandwich wall panels have two ferrocement outer skins and a lightweight inner core portion. The expanded polystyrene plates are readily used in the inner core. Numerous studies were carried out on sandwich panels with EPS inner core. These wall panels were investigated for both with and without shear connectors. The shear connectors are playing a vital role and affect the performance of composite wall and roof panels [11-15]. Several alternative lightweight materials like bamboo, reed, rice straw etc., from the renewable sources and the non-degradable waste materials like plastic wastes, are also investigated for infilling the inner core [16]. The availability, storage and psychological acceptability are the primary issues with these lightweight materials. The insights clearly comprehend that the inner core material is proposed to just fill the gap between the skins. The skins are the component made up of ferrocement, which is expected to carry the loads. The inner core is expected to be light in weight with good sound and heat insulation. The EPS beads are the lightweight material with a density less than 25 kg/m^3. The lightweight concrete can be produced by mixing concrete and EPS beads [17-18].

In view of this, the lightweight concrete is well suitable for the inner core material. The present investigation is carried out to develop a lightweight inner core concrete infilled sandwich wall panel. The material model for the lightweight concrete is distinct from one another due to the various compositions of materials. The present study aimed at developing a material model for the proposed lightweight concrete by modifying the material characteristic of plain concrete. The concrete smeared crack model and damaged plasticity models are found suitable for modeling the behavior of concrete structures [19-20]. The lightweight concrete mix with a higher volume percentage of EPS bead is developed and investigated experimentally. The density, compressive strength and stress–strain

characteristics of lightweight concrete are obtained. The cube is modeled with the material data arrived experimentally. The other parameters required for the analysis were reasonably assumed by trial and error basis. The material model is verified with the experimental results. The second phase of the investigation is carried out on sandwich wall panels with lightweight concrete infill. The sandwich wall panel is cast and tested for in-plane compression loading. The nonlinear finite element analysis is carried with the established material data and compared with the experimental results.

2. EXPERIMENTAL INVESTIGATION

The lightweight concrete is developed by mixing the EPS beads into the flowable concrete. The trial mix is carried out to obtain the mix ratio and obtained a suitable mix ratio, consisting of 1 part of the cementitious material, 1.5 parts of river sand, 1.5 parts of quarry dust and 1.5 parts of coarse aggregate (10-12 mm). A portion of the cementitious material is split into 75% of cement and 25% parts of fly ash. The lightweight concrete is produced by replacing the 75% of normal concrete with the equivalent volume of EPS beads. EPS beads of 3mm sizes are randomly chosen and uniformly sprayed into the normal concrete and mixed thoroughly. The standard cubes of 150mm size and the cylinders of 150 mm diameter are cast and tested in a compression testing machine and obtained its 7th day and 28th day compression strength as shown in Fig. 1. The compressive strength obtained from the cubes and cylinders and utilized for the material modeling. The lightweight concrete cubes are found very light in weight with an average density of 918 kg/m^{3}and it is stable during handling.

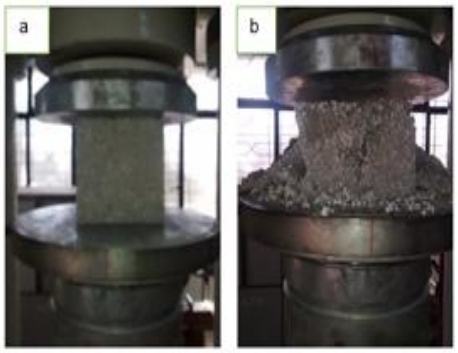


Figure 1. Typical view of lightweight concrete cubes under compression

The observations indicate the suitability of lightweight concrete for infilling sandwich wall panels. The lightweight concrete is developed in the preliminary study is proposed for the inner core material in the sandwich wall panel. A sandwich wall panel of size 1.25 x 1.25 x 0.15 m is cast with lightweight concrete inner core infill. Several mix trials are tried and the concrete mix proportion of 0.75 parts of cement: 0.25 parts of fly ash: 1.6 parts of river sand (passing through 4.75mm): 1.3 parts of coarse aggregate (10-12 mm): 0.36 parts of water cement ratio and 0.5% of superplasticizer is chosen by weight ratio to produce self compacting

concrete (SCC). This concrete mix is used for casting the both 25mm thick ferrocement skins of wall panels and 100mm thick lightweight concrete inner core. The reinforcement cage is fabricated from 16 numbers of 6mm reinforcements in which the individual skins have four numbers of steel rods in each direction with the spacing of 105 mm c/c. A chicken mesh is tied with skin reinforcement to avoid any temperature and shrinkage cracks. Skin reinforcements are tied with Shear connectors. The bottom skin concrete layer is first laid, leveled and maintained uniform skin thickness. The reinforcement cage is placed over the bottom skin concrete. The lightweight concrete for the inner core is prepared in parallel, using another mixer machine. The materials were weighed for a volume equal to 25% of inner core volume and prepared SCC concrete. The 3mm EPS beads of volume equal to 75% by inner core volume are taken and sprayed uniformly into the SCC concrete and obtained a uniform mixer. The prepared lightweight concrete is laid over the bottom skin concrete and leveled. The chicken mesh is tied with top skin reinforcement and over that SCC is placed. The overall panel thickness is maintained to 150 mm. The sequential steps involved in the casting of the lightweight sandwich panel are shown in Fig. 2.

The panel is cured for 28 days and prepared for testing. The panel is weighed and shifted to the test floor for testing. The test specimen is cleaned, whitewashed and grid lines are marked at 4 cm interval. The centerline of loading frame is measured and the positioning panel is marked. Over the marking, wet plaster of Paris paste is applied and the panel is positioned at right location as shown in Fig. 3.

(a) Placing bottom skin concrete (b) Placing chicken mesh and reinforcement gauge (c) placing lightweight Inner core, chicken mesh and top concrete

Figure 2. Typical views of sequences in casting of lightweight concrete infilled wall panel

The vertical and horizontal levels for the test setup were continuously checked. The strain gauges and dial gauges are fixed to observe the response of panel for the in-plane loading. A 2000 kN Enerpac jack is fixed in the loading frame and the load is measured using 2000 kN load cell and cross checked with the pressure gauge fixed in the hydraulic jack. The load is applied in increasing steps and the corresponding response of panel is observed. The strain and the deflection at different locations were observed using the data logger. The cracks developed on the panel surface are marked with a pencil mark and the failure pattern is observed for the comparison.

a. Grid line marking and positioning b. Testing of Panel

Figure 3. Typical view of testing arrangements for testing wall panel

3. FINITE ELEMENT ANALYSIS

The nonlinear finite element is carried out using standard finite element software package. Modeling of concrete composite requires more attention. Experimental tests were conducted and the material characteristics arrived. The present study considers the lightweight concrete as a single material component. The average density of lightweight concrete is obtained. The stress-strain behavior of lightweight bead concrete in compression is obtained from the compression test is shown in Fig. 4a. Damaged plasticity model is used to simulate the nonlinear behavior of lightweight concrete. Based on the physical observations, the lightweight bead concrete has slightly higher lateral expansion compared to the normal concrete. The poison's ratio of 0.33 is assumed for the lightweight concrete as a trailing data. The dilation angle is assumed as 35 degrees and the ratio between equi-biaxial to uniaxial compressive stresses is taken as 1.16. The ratio of the second stress invariant on the tensile meridian to that on the compressive meridian, K is assumed as 0.667. The young's modulus of lightweight EPS beads concrete "E" is obtained by converting the cube strength "f_{cu}" to cylindrical strength "f_{cy}" and substituting the cylindrical strength and the dry density "γ_w" of lightweight concrete into equation.1 [21]. The material characteristics of lightweight concrete are shown in table.1. The average stress and strain result of lightweight bead concrete were calculated and plotted. The cube size of 150 mm with lightweight concrete materials is modeled and analyzed**.** The results obtained from the experimental and analytical investigation of lightweight concrete cubes confirms the material model and hence the material model is used for the inner core of sandwich panel.

$$E = 1.146\,\gamma_{\omega}^{1.1} f_{cy}^{1/2} \tag{1}$$

Table 1: Properties of EPS Bead concrete

Cube Size	f_{cu}	f_{cy}	E (Mpa)	Density (kg/m^3)	Poisson Ratio
150x150x150	0.25	0.1954	898.915	918.0	0.33

The material model for the plain concrete and the steel reinforcements are obtained and

used for modeling the nonlinear behavior of sandwich wall panel. The skin concrete has been modeled with the properties of normal concrete with damaged plasticity model. The normal concrete cubes are tested for comparison and the average compressive strength of normal concrete cubes is found as 31.23 N/mm^2. The density of concrete is taken as 24 kN/m^3, Young's modulus is taken as 25000 N/mm^2 with the Poisson ratio of 0.18. The stress-strain curve obtained for the cylinder is used to model the compression behavior and the tensile behavior of the concrete model is assumed with bilinear behavior. The steel reinforcement is modeled with plasticity model. The material density of steel is assigned as 77 kN/m^3 and Young's modulus is assigned as $2.1x10^5$ N/mm^2. Poison's ratio is assumed as 0.3. The material parameters for modeling the nonlinear behavior of concrete and steel are given in table 2. Both normal and lightweight concrete were modeled with eight nodded brick element (C3D8R). The contact surfaces between the skin concrete part and the inner core portion are modeled with penalty stiffness approach, with a stiffness value 0.1 N/mm^2. Steel reinforcements are modeled with 2-Noded, 3D truss element (T3D2). For cube testing, a 1mm thick plate is placed on top and bottom and tied to the concrete surface. A uniform pressure is applied on top of the panel and the bottom is kept fixed. The static-riks method of structural analysis is carried out. The deflection, stress and strains are observed from the analysis.

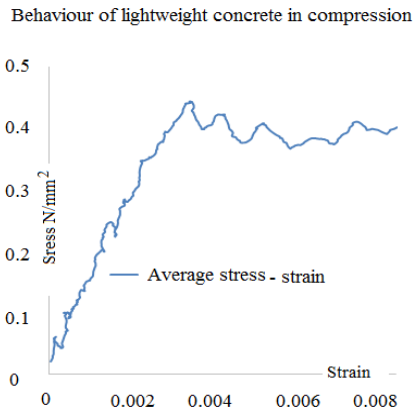
Table 2: Material model for skin concrete, inner core concrete and steel

Compression Model		Tension behavior		Concrete Tension Damage (For both normal & lightweight concrete)		Steel Plasticity	
Stress	Plastic Strain	Yield Stress	Plastic Strain	Damage Parameter	Plastic Strain	Stress	Plastic Strain
12	0	For skin concrete		0	0	340	0
20	0.0007	2.5	0	0.9	0.01	365	0.00015
25	0.0016	0	0.0031			370	0.0003
29	0.002					390	0.001
32	0.0027					430	0.0022
26	0.0029			Note: For damage parameter, 0 represents no damage and 0.9 represents about to fully damaged		435	0.003
						440	0.006
For inner core concrete:		For inner core				435	0.015
Stress – strain curve presented in Fig. 4 is used		0.6	0			400	0.05
		0	0.031			370	0.08

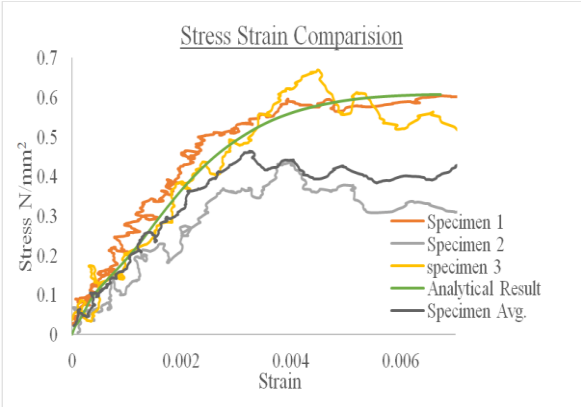
4. RESULTS AND DISCUSSION

The preliminary study carried out with cubes of 150 mm size to develop and evaluate the material model for lightweight concrete. The cubes are loaded uniformly and corresponding displacements are recorded continuously. From the load and deflection observations, the

stress-strain behavior of the lightweight concrete cube is calculated and plotted. The stress-strain graphs obtained from the experiment and the analytical are compared in Fig. 4b. The cubes have behaved in a similar pattern and it confirms the reliability of material model proposed to model the lightweight concrete. The preliminary study on lightweight concrete is not showing any shrinkage cracks and it seems to be dimensionally stable. Further site moldability is the most important advantage of lightweight concrete for the wall panel construction to form any shape and size. The verified material model for the lightweight concrete is proposed to simulate the inner core of sandwich wall panel. The sandwich concrete wall panel is tested under in-plane compression loading as shown in Fig. 5a. The load is gradually applied and the corresponding deflection and strain readings are recorded. The load drops at 600 kN when the first crack is observed. The load is increased further and the panel carries the load steadily. The second load drop is observed at the load to 950 kN.



(a) Average Stress-Strain behavior of lightweight concrete (Input data for model)



(b) Comparision of experimental and analytical results

Figure 4. Comparisons between experimental result and analytical result

The cracks were formed on the vertical edge ("WS" as shown in Fig. 5a) and several micro cracks were formed on the surface ("FS" as shown in Fig. 5b). Further increase in load develops numerous cracks on the vertical edge surface and the skin separation between outer skins and infill layer occurs. The ultimate failure observed from the experiment is 1460 kN with a corresponding compressive strength of 12.87 N/mm^2. The sequential cracking pattern of lightweight concrete infilled wall panel is shown in Fig. 5. Similarly, the performance of sandwich wall panel is analytically studied. The results of numerical investigations are documented and compared with experimental results. The load and the corresponding deflection obtained from the experimental and analytical results are compared and presented in Fig. 6. The maximum load carrying capacity of the lightweight concrete infilled wall panel observed from the analytical model is 1390 kN, which is reasonably comparable with the experimental results, which is 1460 kN. The ultimate load value obtained from the analytical study confirms the effectiveness of material model used for the analysis. The load deflection curve obtained from the analytical study is steeper compared to the experimental results. The slight variation in the result is due to the lacking in the present

analytical model, which does not have the skin separation behaviour. The maximum vertical deflection observed from the experiment is 4.25 mm at the peak load and the deflection obtained from the analytical peak load is 1.96 mm. The concrete panel is very stiff before the formation of the first crack but the deflection reading is increased 1.04 mm excessively at the first load drop at 600 kN.

(a) Crack pattern on edge beam (b) Crack pattern on other side of the panel edge beam (c) Failure pattern on the surface of the panel (d) First crack at 60T on edge beam (e) Micro cracks on surface (f) Failure of edge beam.

Figure 5. Typical view of cracking pattern of panel from crack initiation to ultimate failure

The load deflection plot is corrected at the first load drop and compared in Fig. 6 for the better understanding. The analytical and the corrected experimental results seem to be reasonably comparable. The load and corresponding strain at the different location of wall panel are compared in Fig. 7. The load and the corresponding strains observed from the experimental and analytical results are found comparable. The failure of the panel is observed due to the separation of skins. Both the analytical and experimental results are showed similar pattern of failure. The vertical edges of panel are initially in compression and it becomes tension before reaching the ultimate load. The tension strain in the vertical edge of the panel infers the skin separation. Further, the compression strain in the bottom skin diagonal is increased with the increase of load and it started to decrease before the failure. The analytical and experimental results are slightly varying. The difference observed is mainly due to the cracking and separation of the skins and the inner core lightweight concrete in the experimental study. The analytical model needs to be improved further to include the cracking and the separation behavior of skins. The typical view of cracking

pattern of sandwich wall panel, observed from the experimental and analytical studies are compared in table.3. The failure of the sandwich wall panel with lightweight concrete infill is gradual and several micro and macro cracks are formed before the ultimate failure. The failure pattern observed from the analytical study resembled the experimental results. The analytical model is not predicting the crack opening at different locations and it results in stiffer behavior with reduced deflection than the experimental results. The cracking pattern clearly indicates the deficiency in the shear interaction between the skin concrete layers. This interprets that the shear connector system should be enhanced to avoid the skin layer separation. No bursting or easing out of lightweight concrete is seen from the experiment. The present investigation revealed that the lightweight concrete developed using EPS bead is well suitable for inner core infill. Further, the study proposed a material model for the light weight concrete and validated.

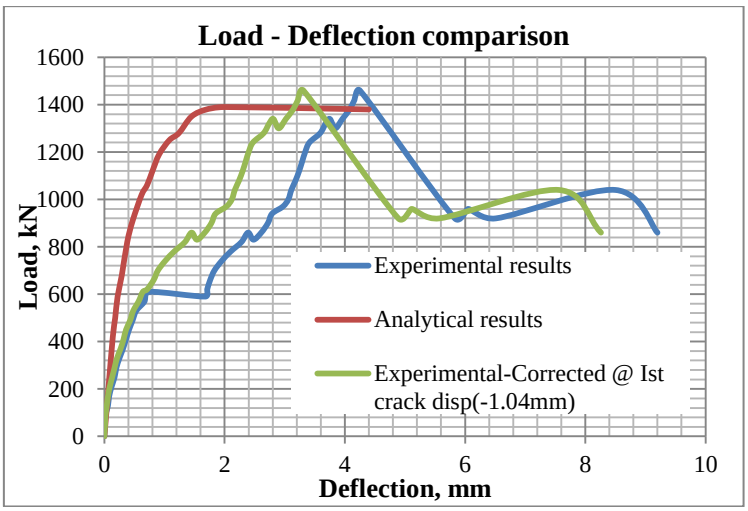
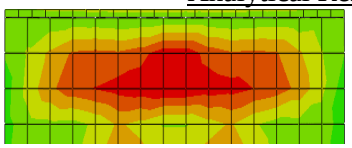
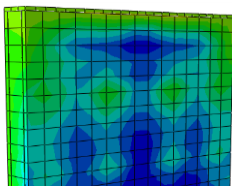


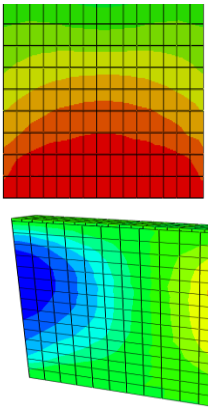
Figure 6. Comparison of experimental and analytical results

Table 3: Comparison of failure pattern of lightweight concrete infilled wall panel

Experimental Results		Analytical Results	
	Spalling of concrete (nearer to top beam)		Maximum principal Stress contours (nearer to top beam)
	Formation of surface cracks at failure load		Plastic strain contours arrived in similar pattern

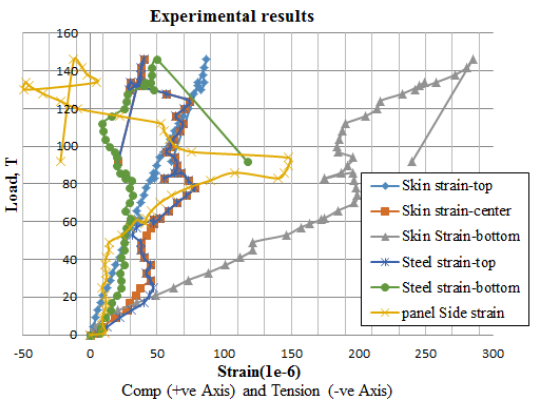
Crushing of bottom

Failure of side due to heavy stress



Similar principal stress distribution observed

maximum stress contour on sides



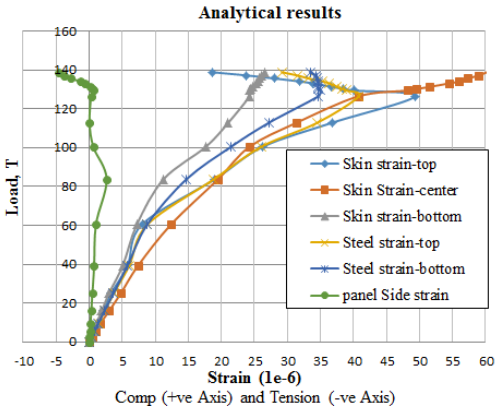


Figure 7. Comparison of experimental and analytical results

5. CONCLUSION

From the experimental and analytical investigation on the lightweight concrete for developing lightweight infilled sandwich wall panels, the following conclusions have arrived.

The present study developed a lightweight concrete with weight density of about 920 kg/m^3. No segregation between the concrete slurry and beads were observed. The maximum strain of 0.007 is observed before the failure with the corresponding compressive stress of 0.5 N/mm^2.

A material model for the lightweight concrete is proposed with the test data and a few assigned trail data. The model well predicted the behavior of lightweight concrete. The material nonlinearity predicted the behavior of light weight concrete infilled sandwich wall panel with reasonable accuracy.

The indigenous development of lightweight concrete for the sandwich wall panel can reduce the cost compared to the existing factory made EPS wall panel. The shape and size of wall panel are more flexible for the sandwich wall panel with light concrete.

The wall panel with lightweight bead concrete infill is performed well. The first crack is

observed at a load about 45 % of the ultimate load. Numerous micro and macro cracks were developed for the increase of load. From the failure pattern, it is inferred that the wall has shown ductile behavior.

The ultimate compressive strength of panel is found about 12.87 N/mm^2 and the compressive strength at first cracking is 4.71 N/mm^2. The result confirms the suitability of lightweight concrete infilled panels for the load bearing and non-load bearing walls. The insufficient shear interaction is observed from the results and it needs to be improved. The present study showed that the lightweight concrete sandwiched with ferrocement skin is well suitable for the wall construction.

The chicken meshes sufficiently confined the sandwich panel. The meshes effectively reduced the concrete spalling out of outer skin layer and it can be a good alternate for welded mesh to reduce cost.

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