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INFLUENCE OF FLYASH ON FLEXURAL STRENGTH OF FERROCEMENT IN CHEMICAL ENVIRONMENT

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***Abstract:* This paper mainly presents a brief study on the effects of fly ash on flexural strength of ferrocement specimens with aggressive chemical environment in which cement is partially replaced in six percentages (0%, 5%, 10%,15%, 20% and 25%) by Class F fly ash by weight and the aggressive chemical environment is provided by adding different concentrations of Hydrochloric acid (HCl) (0mg/l, 250mg/l, 500mg/l, 750mg/l, 1000mg/l) in deionised water during mixing and curing. Flexural strengths at failure (ultimate load) are determined at 7, 28, 90 and 180 days. Test results indicate that the flexural strength increases with the increase of fly ash content up to an optimum value, beyond which the strength values start decreasing with further addition of fly ash. Flexural strength of specimens increase with the increase in mesh layers and width of crack decreases with the increase in number of wire mesh layers and strength of specimens decrease with increase in Hydrochloric acid concentration for a given curing period. Besides the fly ash mortar specimens show better resistance against strength deterioration for all curing conditions and curing ages.**

Keywords: FA-Flyash, OPC-Ordinary Portland Cement, HCl- Hydrochloric acid, ML-Mesh Layers

1. Introduction

Ferrocement is highly versatile form of composite material made of rich cement mortar with layers of wire mesh or with steel rods of smaller diameter closely bound together to create a stiff structural form. It possesses high flexural strength and exhibits lesser crack width when compared to RC elements. It could be moulded into any complicated shape with the skeletal reinforcement provided where ever necessary. This is a versatile material for roofing elements with comparatively lesser thickness than the ordinary RCC slabs. Ferrocement is used in several applications such as water tanks, boats, sunscreens, pre-cast roofing slabs and repair materials etc., Ferrocement construction does not need heavy machinery and highly skilled labours. In construction field ferrocement began almost 60 year back. In 1977, Annamalai.G, Parameshwaran.V.S.& anmuga.V.Sundaram [1] studied on the flexural behavior of ferrocement concrete sandwich Panels. In 1999, behavior of ferrocement beams under shear was studied by M.A.Al-Kubaisy and P.T.Nedwell [2]. In 2002, Kaushik S.K., Pankaj, Akhtar S. and Arif et.al [3] conducted experimental investigations on Ferrocement plates using super plasticized fly ash mortar. In the year 2004, V.Venkateswara Reddy et.al [4], studied on the effects of quality of water on strength properties of ordinary Portland cement concrete and fly ash concrete. In 2007, Raghuprasad P.S., A.V.Pradeep Kumar and R.Nagendra [5] studied effect of chloride penetration and drying shrinkage on blended cement and OPC concrete with reference to marine environment. A Brief experimental investigation on flexural behavior of pozzolanic ferrocement specimens without considering the effect of chemical environment was studied by K.Lakshmipathi [6] in the year 2009. Water is an important ingredient of cement concrete. It not only contributes to the workability of fresh concrete but has active participation in the hydration of cement. Cement which is a complex mixture of compounds which after reacting with water leads to setting and hardening. All compounds in cement form hydrated compounds when it gets reacted with water. Hence the quality of water has most significant effect in arriving at or getting the strength to cement gel. Naturally available water contains numbers of dissolved impurities like acids, salts in varying concentrations. Generally the standard of water that is used for making either concrete or mortar should be potable. I.S. 456-2000, specifies the minimum p^H value as 6.0 and also permissible limits for solids in water to be fit for construction purpose.

But the water which is fit for drinking purpose may not be always be available abundantly for mixing and curing. And also some water which is locally available may not be fit for drinking and is inevitable to use in the mix. Some condition of the environment leads to acidic or may contain salts at which the structure with cement concrete may affect in its strength. The ferrocement members as they are thin may get affected in their structural behavior due to the above reasons. To study the effect of addition of pozzolana on the chemical environment, to reduce the heat of hydration and due to economic reasons now a days cement is being replaced partially with the pozzolanas which are usually industrial wastes such as metakaolin, silica fume, fly ash etc., The effect on the strength properties of mortar when the cement is replaced partially by fly ash and used in various types of chemical environments is to be given due consideration. The present paper, therefore, attempts to provide essential information on the flexural strength of various percentages of pozzolanic (fly ash) ferrocement plates made and cured with different magnesium sulphate concentrations for long term ages.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Cement

Ordinary Portland (43 grade) cement of ACC Brand was used. It was tested as per Indian Standards Specifications IS: 8112-1989. Its properties are specific gravity of 3.13, normal consistency of 33%, fineness of 5%, initial setting time is 54 minutes and final setting is 342 minutes.

2.1.2 Fine Aggregate

The locally available pandameru river natural sand was used as a fine aggregate. It was tested as per Indian Standard Specifications IS: 383-1970 and its fineness modulus is 2.78.

2.1.3 Fly Ash

Class F fly ash obtained from Rayalaseema Thermal Power Station (RTPS), Muddanuru, Kadapa District, A.P. India was used in this investigation.

3. VARIABLES STUDIED

(a) Mortar quality: The mix ratio of cement: sand 1:3 with w/c ratio of 0.50 was adopted. Cement was partially replaced by fly ash in six different percentages of 0%, 5%, 10%, 15%, 20% and 25%.

(b) Size of Specimens with No. of Mesh layers: Plates of size 970mm x 300mm x 35mm with varying number of wire mesh layers of 1,3,5 in tension zone for flexural strength test were cast and tested.

(c) Mixing and Curing environment: Four different concentrations of HCl (250 mg/l, 500 mg/l, 750 mg/l and 1000 mg/l) were adopted during the mixing in the deionised water and cured in same concentration of water.

(d) Exposure period: Specimens were tested periodically after the specified curing periods of 7, 28, 90 and 180 days.

A total number of 1080 ferrocement plates were cast in the laboratory. After 24 hours, all the specimens were demoulded and cured in water in a curing tank at room temperature. After specific exposure period, specimens were tested for flexural strengths under two point loading as shown in Fig-1 through a 5 Tons precalibrated proving ring. Three dial gauges were used as shown to measure the deflections. All specimens were tested up to failure.

4. RESULTS AND DISCUSSION

Table 1 shows the flexural strength at failure with various number of mesh layers for various percentages of fly ash and prepared with different concentrations of HCl at 7, 28, 90 and 180 days.

4.1 Behavior of ferrocement with fly ash admixture on Flexural Strength:

The variation of flexural strength at ultimate failure versus age in curing in days for various percentage replacements of cement by fly ash and for given number of mesh layers is shown in Fig-2. The variation of flexural strength at failure versus age for various number of meshes layers and for given percentages of fly ash replacement is shown in Fig-3. From these diagrams, it is observed that all the flexural strength at failure for all percentage of fly ash and for any number of mesh layers increase from 7 days to 28 days drastically and afterwards also increases up to 180 days but at a slower rate. Also all strengths are found to increase with the increase in number of mesh layers.

The variation of flexural strength at failure Vs percentage of fly ash replacement for various ages and for given number of mesh layers is shown in Fig-4. From this diagram, it may be observed that the flexural strength at failure for given number of mesh layers at 7 days curing period almost decreases with the increase in fly ash content slowly due to slower Pozzolanic reaction of fly ash at early age. The flexural strength at 28 days, 90 days and 180 days increases with fly ash content up to 10% optimum replacement and then reduces slowly with increase of fly ash content.

The strength development at the early age is lower but at later ages, that is, at 28, 90 and 180 days, there is considerable increase in compressive strength of blended concrete compared with early age (7 days) strength. This may be due to the fact that there is pozzolanic effect of fly ash and the gel formation like C-S-H/C-A-H fills in the pore generated by liberation of $Ca(OH)_2$ during hydration of OPC concrete. All these activities enhance the bonding inside the concrete matrix and thus the strength increases. The variation of flexural strength at failure Vs percentage of fly ash addition for various number of mesh layers and for given age of curing is shown in Fig-5. This diagram indicates that more number of mesh layers would have more flexural strength.

The variation of flexural strength at failure versus number of mesh layers incorporated in the tension zone of the flexural specimens for various ages of curing periods and for given percentage of fly ash is presented in Fig-6. The variation of flexural strength at failure versus number mesh layers for various percentage of fly ash and for given age of curing period is presented in Fig-7. From these Figures, it is noted that for all ages of curing and for any percentage of fly ash the flexural strength at failure increases with the number of layers of wire mesh.

From the table 1, it may be observed that the specimens of 10% fly ash content with 5 layers of chicken mesh at 180 days of curing yield optimum flexural strength at ultimate load.

4.2 Load Vs Deflection at Center of Flexural Plates :

In this investigation load-deflection variations using (P-δ diagrams) for number of variables were also studied. Here the maximum deflection observed at the ultimate load i.e., where the pointer of proving ring gets reversed. It may be observed that the variation is almost linear up to first crack load and afterwards it deviates from linearity.

With the increase in number of wire mesh layers the variation is maximum. It is also observed for the specimens with maximum number of wire mesh layers with the increasing percentage of fly ash (up to optimum of 10%) the P-δ variation is increasing and afterwards the variation gets declined for higher percentage of fly ash beyond 10%. Hence within the preview of percent investigation and from the above observations, it may be under stood that with the more number of mesh layers and optimum content of fly ash the ductility and load carrying capacity of the ferrocement specimens get enhanced.

4.3 Cracking and Failure Pattern of Flexural Plates :

For almost all the specimens it was commonly observed during the testing of ferrocement specimens in the flexure the cracks are found to initiate at the bottom of the middle portion of the specimen or in other words, the first cracks have appeared at the mid span of the flexural specimen at bottom as shown in Plate 1. As the load was increased further already formed cracks got widened and more and more new cracks have formed. . Some cracks have extended towards the top compression zone with the increase of load. The majority of cracks are formed at middle of the beam in Flexural tension zone. Very few cracks appeared in shear zone also. It indicates that the beam has failed predominantly in flexure. It is observed form the visual observation that the beams have failed predominately in flexure.

During testing it was observed that all most all the specimens with one layer of wire mesh failed suddenly due to poor ductility without any clear warning, as the number of wire mesh layers was increased the ductility got increased and specimens failed by showing sufficient warning. The sample crack pattern of different specimens is presented in Plates 2 to 4. During testing it was observed that the maximum crack width is found to decrease with increase in the number of layers of mesh reinforcement. Lowest crack width was observed for the case of five layers of mesh reinforcement. This phenomenon is due to the role of the mesh in holding the mortar matrix together and offering resistance for widening of crack in the mortar matrix. Also observed that the spacing of tensile cracks to be closer and crack-width smaller, which indicates that the crack arresting mechanism, is better, as the number of layer of mesh reinforcement increases and distributed through the entire thickness of the ferrocement specimens.

4.4 Effect of Hydrochloric acid (HCl) on flexural strength of ferrocement with fly ash samples:

The variation of flexural strengths versus concentration of HCl for various ages of curing in days for given percentage of fly ash and for given wire mesh layers are presented in Fig-8. Also the variation of flexural strengths versus concentration of HCl for various percentages of fly ash with given age of curing and for given wire mesh layers are presented in Fig-9. Similarly the variation of flexural strengths versus concentration of HCl for various number of mesh layers for given percentage of fly ash and for given curing days are presented in Fig-10. From these Figures it is seen that with the increase in concentrations of HCl, the flexural strength at ultimate load is found to decrease. Finally from the results, it is also observed that the deterioration of concrete or mortar in strength is decreased with increasing the fly ash up to optimum value. It indicates that the pozzolanic fly ash mortar resists acid attack to some extent.

The reaction of mortar with water containing HCI leads to the formation of chlorides of calcium and aluminum in addition to Hillebrandite $[Ca_2(HSiO_4)(OH)]$. Among these, chlorides of calcium and aluminum are soluble. Even silica forms a colloidal solution. Significant decrease in strengths is noticed due to the formation of soluble chlorides. Acid attack can also cause progressive loss of strength due to deterioration in the cohesiveness of the cement hydration products.

Pozzolanic materials such as fly ash improve the microstructure of concrete or mortar due to their particle size, and may alter chemical composition and hydration reactions. The effectiveness of blended cement materials in reducing the level of damage from sulfate attack has been studied for decades; yet, the role of chemical composition of pozzolanic materials needs to be more precisely studied. Reduced ionic diffusivity and decreased C3A availability are the major reasons that improve the sulfate resistance in blended cements using fly ash.

5. CONCLUSIONS

Based on the results of the investigation conducted on different fly ash ferrocement flexural specimens made with various levels of cement replacements with different concentrations of HCl and cured for various curing periods up to 180 days, the following conclusions can be drawn:

1. The flexural strength of ferrocement specimens increase with the addition of fly ash up to an optimum content 10% and afterwards decreases.
2. The load-carrying capacity in at ultimate load of ferrocement panels show higher values with the increased number of mesh layers.
3. The conventional mesh reinforcement (chicken wire mesh) plates exhibit linear-elastic behaviour (i.e., with respect to load Vs deflection), up to the first crack load, irrespective of the number of layers of mesh reinforcement used and afterwards deviate from linearity.
4. The addition of chicken mesh wire layers have improved the ductile behavior of ferrocement specimens.

5. Incorporation of mesh layers in the tension zone as reinforcement in ferrocernent panels has contributed significantly in improving the crack arresting behaviour under flexure. On reaching the maximum load (under flexure), the above type of panels exhibit cracks those are possible to be easily identified by the naked eyes, then there is slow propagation i.e., progressive cracking behaviour. However, brittle failure is exhibited in specimens without mesh layers or with lower number (single) of mesh layers. But, the cracked specimens do not separate into various pieces and that there is reduction in the crack width, when more number of mesh layers are incorporated. The above behaviour is clearly due to the contribution of number of mesh layers, which has helped to bridge the cracks those have developed and prevent breaking of the specimens. Increasing the mesh layer of reinforcement leads to decrease in average crack width.
6. All flexural specimens mostly have failed due to flexural cracks i.e., cracks are initiated at the bottom of the mid span which are mostly in flexure zone.
7. Ferrocement panels with the replacement of cement by 10% of fly ash and with 5 layers of chicken mesh layers have shown around 21.53% higher flexural strength at 1st crack than those of OPC mortar after 180 days of curing. The corresponding increase in flexural strength at ultimate load is observed to be around 34.63%.
8. All strengths are decreased as the concentration of HCl is increased in water for given age of curing period. However, in a lower concentration, there is no remarkable difference in the deterioration of mortar specimens, even up to 180 days of exposure, regardless of replacement levels of fly ash.
9. Strengths of all specimens decrease with the increase in curing period for the given concentration of HCl.
10. Deterioration in strength is more for higher concentrations of HCl and later ages of curing.
11. Strength deterioration of mortar due to acid attack gets decreased with the increasing the fly ash content up to optimum value. i.e., the pozzolanic cement mortar specimens reflect better chemical resistance up to an optimum content.

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Plate-1 Initiation Of Flexural Cracks At Bottom

Plate-2 View Of Crack Pattern Of Flexural Plates With 1 Layer Of Wire Mesh

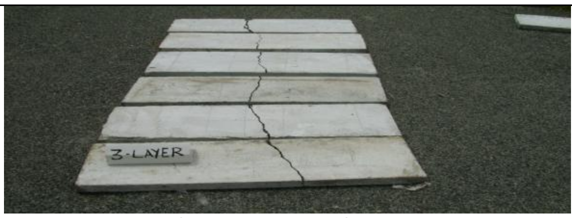


Plate-3 View Of Crack Pattern Of Flexural Plates With 3 Layer Of Wire Mesh

Plate-4 View Of Crack Pattern Of Flexural Plates With 5 Layer Of Wire Mesh

Table-1 Flexural Strength at Ultimate Load in N/mm^2 for different variables of Fly Ash and Concentration of HCl

% of FA	Concentration of HCl in mg/l	No. of Mesh layers	Flexural Strength at Ultimate Load in N/mm^2				No. of Mesh layers	Flexural Strength at Ultimate Load in N/mm^2				No. of Mesh layers	Flexural Strength at Ultimate Load in N/mm^2			
			7 days	28 days	90 days	180 days		7 days	28 days	90 days	180 days		7 days	28 days	90 days	180 days
0	0	1	0.98	1.57	1.93	2.31	3	1.10	1.77	2.24	2.62	5	1.21	2.06	2.57	3.11
0	250	1	0.87	1.46	1.77	2.00	3	1.03	1.57	2.06	2.39	5	1.08	1.85	2.31	2.75
0	500	1	0.87	1.39	1.67	1.90	3	0.95	1.54	1.95	2.31	5	1.05	1.80	2.21	2.65
0	750	1	0.82	1.36	1.62	1.80	3	0.90	1.49	1.82	2.11	5	1.05	1.70	2.06	2.49
0	1000	1	0.82	1.28	1.57	1.77	3	0.87	1.39	1.75	1.95	5	1.00	1.62	2.00	2.36
5	0	1	0.90	1.80	2.21	2.62	3	1.08	2.00	2.52	2.98	5	1.13	2.31	2.88	3.57
5	250	1	0.80	1.70	2.06	2.39	3	1.00	1.85	2.31	2.72	5	1.05	2.11	2.59	3.16
5	500	1	0.80	1.67	2.00	2.31	3	0.92	1.80	2.26	2.65	5	1.00	2.06	2.54	3.13
5	750	1	0.72	1.62	1.95	2.11	3	0.87	1.70	2.16	2.54	5	0.95	1.95	2.36	2.88
5	1000	1	0.72	1.52	1.80	2.06	3	0.82	1.67	2.06	2.44	5	0.90	1.88	2.31	2.77
10	0	1	0.72	2.00	2.52	2.98	3	0.98	2.21	2.75	3.34	5	1.03	2.54	3.24	4.01
10	250	1	0.67	1.90	2.39	2.83	3	0.90	2.11	2.59	3.13	5	0.98	2.34	2.95	3.62
10	500	1	0.64	1.85	2.31	2.70	3	0.85	2.06	2.54	3.01	5	0.95	2.29	2.88	3.53
10	750	1	0.64	1.80	2.26	2.54	3	0.85	1.88	2.44	2.95	5	0.92	2.16	2.72	3.31
10	1000	1	0.62	1.70	2.11	2.36	3	0.82	1.85	2.31	2.77	5	0.90	2.11	2.67	3.21
15	0	1	0.54	1.67	2.16	2.47	3	0.82	1.85	2.47	2.80	5	0.87	2.26	2.93	3.39
15	250	1	0.49	1.57	2.00	2.21	3	0.77	1.70	2.21	2.59	5	0.80	2.11	2.70	3.06
15	500	1	0.46	1.54	1.95	2.11	3	0.70	1.64	2.16	2.44	5	0.75	2.00	2.54	2.88
15	750	1	0.46	1.49	1.85	2.06	3	0.64	1.62	2.11	2.36	5	0.72	1.95	2.44	2.77
15	1000	1	0.46	1.39	1.75	1.95	3	0.64	1.52	2.00	2.26	5	0.72	1.85	2.31	2.70
20	0	1	0.46	1.28	1.62	1.90	3	0.64	1.44	1.82	2.11	5	0.75	1.62	2.00	2.62
20	250	1	0.41	1.18	1.49	1.67	3	0.57	1.31	1.62	1.90	5	0.69	1.46	1.80	2.31
20	500	1	0.41	1.18	1.44	1.62	3	0.57	1.26	1.57	1.80	5	0.67	1.36	1.70	2.21
20	750	1	0.39	1.10	1.36	1.52	3	0.51	1.21	1.52	1.77	5	0.67	1.34	1.67	2.16
20	1000	1	0.39	1.05	1.31	1.49	3	0.51	1.13	1.41	1.67	5	0.62	1.28	1.57	2.11
25	0	1	0.39	1.08	1.31	1.67	3	0.59	1.21	1.49	1.85	5	0.64	1.39	1.64	2.26
25	250	1	0.33	1.00	1.18	1.44	3	0.46	1.08	1.31	1.72	5	0.59	1.23	1.46	1.95
25	500	1	0.33	0.95	1.13	1.39	3	0.46	1.05	1.23	1.57	5	0.57	1.23	1.36	1.85
25	750	1	0.31	0.90	1.08	1.31	3	0.46	1.00	1.21	1.46	5	0.57	1.21	1.31	1.80
25	1000	1	0.31	0.87	1.05	1.23	3	0.44	0.98	1.13	1.44	5	0.51	1.13	1.28	1.75

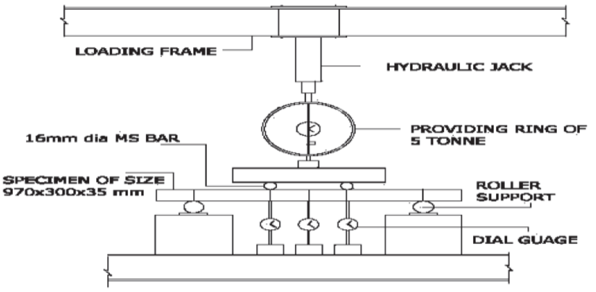
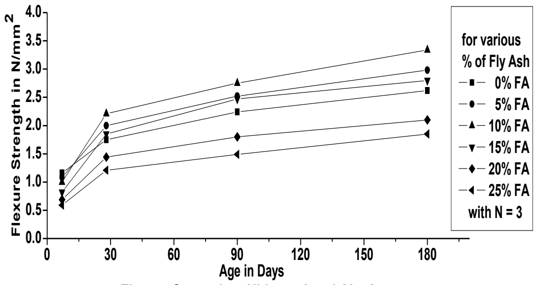
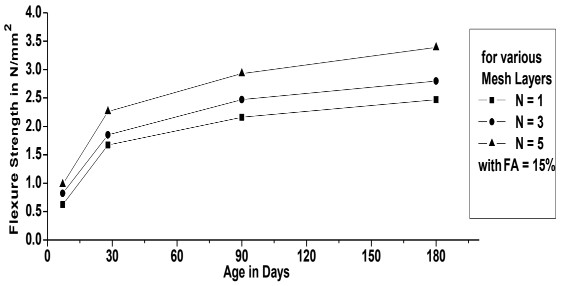


Fig: 1 Elevation of Loading Arrangement



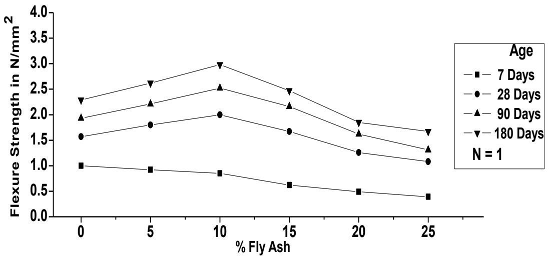
Flexure Strength at Ultimate Load Vs Age

Fig: 2



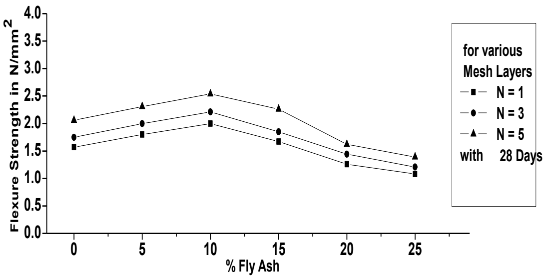
Flexure Strength at Ultimate Load Vs Age

Fig: 3



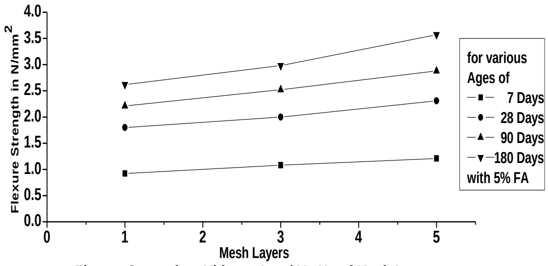
Flexure Strength at Ultimate Load Vs % Fly Ash

Fig: 4



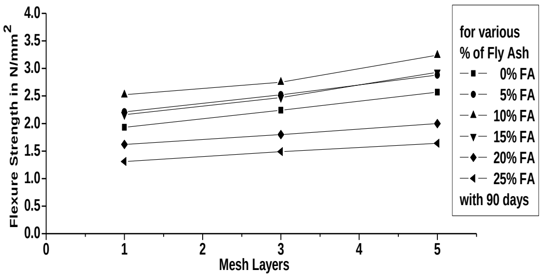
Flexure Strength at Ultimate Load Vs % Fly Ash

Fig: 5



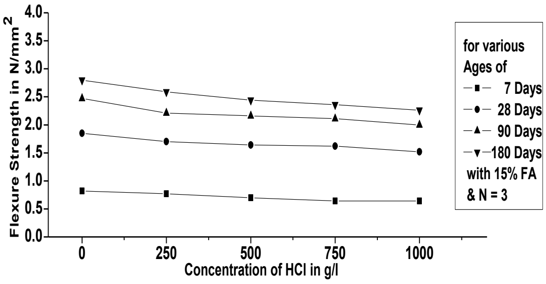
Flexure Strength at Ultimate Load Vs No.of Mesh Layers

Fig: 6



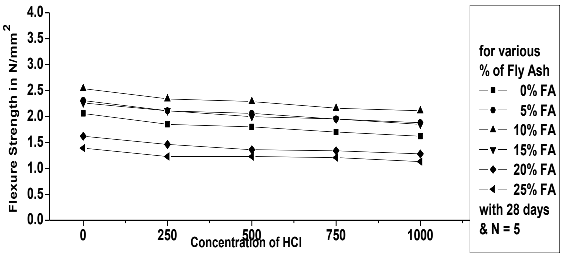
Flexure Strength at Ultimate Load Vs No. of Mesh Layers

Fig: 7



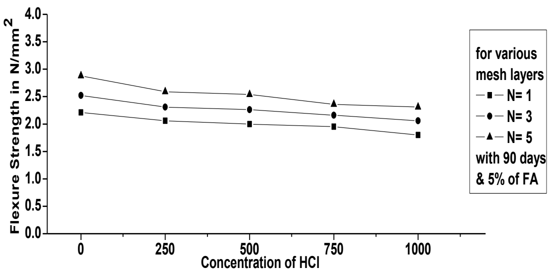
Flexure Strength at Ultimate Load Vs Concentration of HCl

Fig: 8



Flexure Strength at Ultimate Load Vs Concentration of HCl

Fig: 9



Flexure Strength at Ultimate Load Vs Concentration of HCl

Fig: 10

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