Concrete Block Masonry Bond Strength

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SUMMARY

As bond strength of clay bricks and mortar has previously been investigated and reported by many authors, this work was directed to the bond strength of mortar and concrete blocks. The aim of this research was to determine the effect, if any, of the following factors on masonry bond strength. These factors are:

(i) Temperature of casting and curing
(ii) Mortar Flow
(iii) Age of a Mortar when used
(iv) Static load on a Joint

All mortar mixes contained sand, cement, water and carboxy methylcellulose mixture. The influence of these factors was studied by casting a series of wallettes and determining the bond strength of the joint. Standard tests were also carried out on each mortar and the blocks used in the wallettes.

The results show a high temperature bond strength problem. The report concludes that to obtain optimum bond strength, a balance must exist between block IRA and mortar water retention.

1. INTRODUCTION

Bond strength is the property that imparts strength to a block wall subjected to lateral loads. The wind forces are the most common form of lateral load on a building, and therefore, it is imperative to achieve good bond strengths in masonry construction.

Traditionally, a mortar mix of one cement, one lime and six sand has been used to lay concrete blocks. The sand in the Brisbane area was always a "brickies sand". This sand contains a high proportion of fines and is loaded with organics. Less than satisfactory bond is obtained with this mortar. The relevant code AS 1475 Part 1, gives the average bond strength requirement of 0.28 Mpa. With a factor of safety of four, an allowable working bond stress of 0.07MPa is obtained. The AS 1475 Code Amendment, released in September 1983, states higher bond strengths can be used in design provided they are backed by test data. The Code Amendment also states bond strengths can be improved using a mix of one cement, five sand and 0.003 to 0.005 parts carboxy methylcellulose admixture. A clean, sharp, washed pit sand is specified.

In the future, it is hoped the factor of safety will be lowered and the characteristic bond strength requirement increased. To allow this, the mechanism of bond must be fully understood. Engineers must be confident that bond strengths will continually fall in the specified range before using them in design. There are many factors which affect the bond strength and some of these have been investigated in this research.

2. PAST RESEARCH INTO BOND

The influence of temperature has not been investigated in past research. Gairns finds increasing curing temperature is accompanied by a decrease in bond strength. These tests were done under field conditions so the effect of initial rate of absorption of the blocks (IRA), relative humidity, and the presence or absence of wind is unknown. Gairns concluded that the poor bond strengths obtained at high temperature were due to the lack of adequate curing caused by a rapid drying out of the joint. This meant insufficient moisture was available for adequate hydration of the mortar.

In contrast to the finding, Von Rensburg, Kloppers and Kruger state "the bonding strength of the piers was somewhat lower than that obtained previously for similar piers because of the exceptionally low temperatures during the time the latter piers were built and cured."

Research by Bacon concluded that the heat of the sun on blocks and mortar significantly reduced bond strengths. Laboratory and outdoor tests were performed to compare bond strengths. It was found on all but one occasion that the laboratory strengths were much higher than outdoor strengths. These tests gave no account of the IRA of the blocks used in the laboratory compared to those used in the field. No record of temperature at which the wallettes were built or tested was kept.

Gairns also noted the effect of mortar flow on bond. His results show an increase in average bond strength from about 0.3 MPa at 95 per cent flow to approximately 0.6 MPa at 125 percent flow. The temperature at which these tests were performed was not noted. Other points concluded by Gairns were:-

(a) higher cement contents of the mortar lead to higher bond strengths.

(b) the pressure applied to a block while being laid influences the bond strength

(c) dust on the mortar/block interface can affect bond to a significant extent.

Johnston has found what is thought to be the best mix for masonry blockwork in order to gain high bond strength. His recommendation is a mix which is now included in the Blockwork Code. The sand should be free of organics and have less than five percent passing the 150 micrometer seive. A series of tests established this as the best mix design. The test results show no record of temperature at the time the blocks were cast. The mortar flow used was mentioned only occasionally. One mix used an 89 percent flow and another used an 81 percent flow. Clearly, the mortars used were at the bottom end of the permissible flow range. AS 1475 Part 1 states that the first flow should be in excess of 85 percent.

Findings by Von Rensburg, Kloppers and Kruger agree with those of Johnston. It was found that bond strength decreased as the percentage of material passing the 150 micrometer sieve increased.

Copeland and Saxer concluded that the flexural bond strength of mortars increases with their compressive strengths. It was also noted that flexural bond strength decreased with increasing air content of the mortar, and that increasing the initial flow of mortar from 120 to 140 per cent generally resulted in a higher tensile bond strength.

The past research has at times, led to conflicting reports of what should and should not be done to obtain good bond. In some cases, bond strengths have been determined to be a function of one variable when sufficient control tests have not always been carried out to ensure no other factor is affecting the bond. There appears to be a consensus of opinion that increasing mortar flow increases bond strength, and that high temperature decreases bond strength. Insufficient control test data exists to determine exactly what causes these fluctuations on bond strength.

3. EXPERIMENTAL WORK

The test program involved the construction of wallettes and then breaking them at seven days, as specified in AS 1475 Part 1. The blocks were the 10.01 series. These have the mean dimensions of 390mm long by 190mm high by 90mm wide. These blocks have a disadvantage over other block sizes in that the smaller cores on the 10.01 blocks allow formation of a mechanical bond. An increase in bond strength is noted over that which would be obtained with a 20.01 block where the cavity is too large to allow formation of a mechanical bond. A professional blocklayer was employed to build all the wallettes. This ensured uniformity of joints. Unfortunately, due to circumstances beyond the laboratory's control, a different blocklayer was used to build the 10 degree wallettes and those at the other three temperatures. Both men were very experienced tradesmen, and the changing of the blocklayer should not have affected the results.

3.1 Test Programme.

A test programme was structured to test the effect that different factors had on mortar bond strength. These factors were:

(a) Temperature at which wallettes were cast and cured

(b) Flow of the mortar used in the joints

(c) Age (time after mixing stopped) of the mortar when used in a joint.

(d) Static load on a mortar joint.

A series of control tests were performed on the blocks and mortar throughout the project. The purpose of this was to try and pinpoint the reason for any change in bond strengths.

A constant relative humidity was kept for all tests. The relative humidity chosen was 61 per cent, the average for Brisbane for the year. The temperatures selected were 10, 20, 30 and 40 degrees celsius. Keeping a constant relative humidity meant that the amount of water vapour in the air changed with the temperature. Although the temperature was being tested, it was therefore not independent of water vapour effects. To keep this effect out of the programme would have involved keeping a constant amount of water vapour in the air, or a constant absolute humidity. As can be seen on a psychromatic chart, this would involve a range of climatic conditions unlikely to be experienced. For this reason, the effect of water vapour was introduced to keep the range of temperature and relative humidity to realistic figures. An environmental room was used to give these combinations of temperature and humidity.

All of the materials to be used in the construction of the wallettes were placed in the environmental room at least 48 hours prior to the day of construction. This allowed all materials to reach a steady state condition with the temperature and relative humidity.

Three flows were selected for the mortar. The flows were 100 percent, 130 percent and 150 percent. This amounted to a dry mix, a normal consistency and a very wet mix. To test the bond strength variation, ten wallettes were built with each type of mortar at each temperature. This gave 30 joints per mortar flow at each temperature, and 90 joints per temperature.

3.2 Control Tests.

A number of control tests were performed on each mortar. The mortar flow was measured using a flow table and 25 drops in 15 seconds of the table. Water was added to the mortar until the specified flow for a particular batch of wallettes was obtained. The wallettes were constructed using this mortar and a number of other tests were performed on the mortar as control tests.

The other tests performed on the mortar were as follows:

(a) Water retention

(b) Compressive strength

(c) Air entrainment.

Water retention is the flow after suction expressed as a percentage of the flow before suction. The code requires the pre-suction flow to be 110 $\pm$ 5 percent. This was not followed as the water retention of the mortar as used was required. The pre-suction flows of 100, 130 and 150 percent were tested.

The compressive strength of the mortar was measured by using a cylinder of mortar of 70mm diameter and a length of twice the diameter. These cylinders were crushed in the normal procedure for concrete cylinders.

Air entrainment was measured in the normal method to see if there was any great variation in the percentage of air in the mortar. If possible, the air entrainment was kept at a constant percentage for all mortar mixes.

The initial rate of absorption (IRA) of a block is a measure of its suction, that is, the strength of the block's ability to draw water from the mortar. The test procedure which followed differed from that in the code in that the code requires the use of oven dried blocks, but the blocks were tested as used in this programme. The purpose of this was to measure the IRA of the blocks subject to the same temperature and humidity as those being laid. At each temperature, a total of 12 blocks were tested for IRA. Six were tested on the top face and six on the bottom face.

4. TEST RESULTS.

4.1. Flow Test:

The water content of the mortar was adjusted until the required flow was obtained. It was a trial and error problem because the flow was very sensitive to fluctuations in water.

4.2. Water Retention:

The results of these tests are shown in Table 1. It can be seen that the results at 10 degrees are significantly lower than the results obtained for 20, 30 and 40 degrees celsius. The results at these latter temperatures are fairly consistent and in the 70 to 85 percent range.

4.3. Compressive Tests:

The results of the compressive strength tests are given in Table 1 as a mean strength and characteristic compressive strength for each flow and each temperature. The cylinder compressive strength results show the 10 degrees results to be higher than those at other temperatures. In all but one case, the compressive strength decreases as the flow is increased. The cylinder densities show no great variations so all are compacted to a similar extent,.

4.4. Block IRA Test:

The IRA of blocks was calculated and is shown in Table 2. It is seen that there is little variation between the results at 10, 20 and 30 degrees. The values at 40 degrees are approximately 20 percent of those at the other temperatures. This occurred for both the top and bottom of the block. As the 40 degree results were so much lower, the test was repeated to check for the possibility of a gross error. Results of a similar magnitude were again obtained. The IRA for the bottom of the block is consistently lower than that for the top.

4.5. Bond Strength Results:

Bond strength results were examined to compare the different factors affecting bond. A summary of results is shown in Tables 3 and 4. In all comparisons of results, the 96 percentile or characteristic strength values are used. The characteristic strength is calculated by:-

$$X = \bar{x} - K_3 S.$$

where X is the characteristic strength.

$\bar{x}$ is the mean value

S is the standard deviation of results

k_3 is the sample size factor from the Draft Masonry Code.

4.5.1. All Results Considered:

Initially, all results were taken into consideration. Characteristic strength values are shown in Tables 3 and 4 and a graph of results in Figure 2.

It is seen that the value obtained for the 150 percent flow at 10 degrees is significantly higher than for the other two flows. At 20 and 30 degrees, the results are less scattered and the bond strengths appear to be at somewhat of an optimum. A significant decrease in bond strength is evident at 40 degrees. All average bond strengths are above the 0.28 MPa as specified in the Code Amendment. The lowest average bond strength is 0.33 MPa for the 150 percent flow at 40 degrees.

4.5.2 Time after Mixing Considered:

In this analysis, bond strengths are considered in relation to the time after completion of mixing that the mortar was used in a joint. Eighteen joints were completed in the first 45 minutes and the remaining twelve joints in the next 30 minutes from the same batch of mortar. The results of the first 18 joints are shown in Tables 3 and 4 and a graph of results in Figure 3. The same general trend is seen for these results as can be seen in the total results for each mix. The conclusion to be drawn from these results is the general decrease in bond strength as the time after completion of mixing increased.

4.5.3. Static Pressure on the Joint Considered:

The results of bond strength for the top, middle and bottom joint in the wallettes were compared for each of the flows, independent of the mortar age. The results are in Tables 3 and 4 and the results are plotted on graphs shown in Figures 4, 5 and 6. No trend is present in the results.

5. DISCUSSION OF TEST RESULTS.

Flow can be used as a measure of the mortar's consistency and also its workability. The blocklayers gave their preference to the 130 percent flow, saying it was among the best mortars with which they had worked. They felt that the 100 percent was too dry and was difficult to spread over the bedding surface. The 150 percent was slightly too wet and was a little difficult to keep on the bedding surface.

The lower water retentivity values at 10 degrees can be explained by the behaviour of the additive. When used in this project, the additive had a low temperature solubility problem. At low temperatures, not all of the additive was being dissolved. The greater the amount of water in the mortar, a higher proportion of the additive present could be dissolved. The beneficial effects of the admixture to water retention would be more pronounced at a higher flow.

All water retention values exceeded 70 percent excluding the 10 degree results. AS 1475 Part 1 suggests a minimum water retentivity of 70 percent for concrete masonry mortars.

It should be noted that the Code suggested minimum value of 70 percent is for the initial flow of 110 $\pm$ 5 percent. In these tests, flows up to 150 percent have been used as initial flows. Higher flow mortars tend to give up water more easily under suction than low flow mortars. A water retention slightly lower than 70 percent is therefore acceptable for high initial flow mortars.

The compressive strengths of the mortar at 100 percent flow had a higher strength than the other flows due to their lower water to cement ratios. This trend is evident in all the results.

Air entrainment is of significance to bond strength because the bond is reduced as the percentage of entrained air increases. This reduction is caused because the density of the mortar surface presented to the block is reduced by the presence of a large number of minute air bubbles. It is therefore desirable for air entrainment to be as low as possible from the strength point of view. Entrained air is required in a mortar to give the mix some workability. The trapped air reduces the surface tension of the mixing water thereby increasing its wetting action and causes frictionless aggregate to be incorporated in the mix in the form of microscopic air cells. The entrained air in mortar will usually be in the range of 10 to 20 percent.

The block IRA results show the very significant decrease in block IRA at 40 degrees compared to the results obtained at the other temperatures. Relative humidity is defined as the ratio of the actual mass of water vapour in a given volume of air to that which it would have if it were saturated at the same temperature. As air temperature increases, the

amount of water vapour it requires to become saturated is larger. For a constant relative humidity of 61 percent in the controlled environmental room, the actual amount of water vapour in the air will increase as the temperature is raised from 10 to 40 degrees celsius. As the block reaches a steady state condition with the environment, it should contain more water at 40 degrees than at 10 degrees. Hence, the block will take up less water at 40 degrees than at 10 degrees, so the IRA will be less.

All methods of analysis showed the highest bond strength to occur at 10 degrees with the 150 percent mortar flow. Excellent bond strengths were obtained with the characteristic bond strength value for the mix up to one half an hour old of 0.58 MPa. It may be that 10 degrees is the optimum temperature for obtaining good bond, but because of the admixture solubility problem, this was not shown by the results for the other flows. At 10 degrees, the water retentivity of the mortars was low. This could reduce the bond strengths by allowing too much water out of the mortar and into the block. Insufficient water would be available for the mortar in the joint to hydrate properly.

At 40 degrees, the blocks had a very low IRA and the mortar a reasonable water retentivity. The bond strengths obtained were low. The low bond strengths are due to a combination of the low block IRA and the high water retentivity value. The blocks couldn't absorb sufficient water from the mortar to create a strong bond. What was occurring is evidenced by the break position which was predominantly along the bottom of the joint. Little water was absorbed from the mortar by the bottom block prior to placing the top block. The top block had ample water available and it drew out all it could, forming a weak bond. Meanwhile, the remainder of water within the joint flowed under gravity onto the top surface of the bottom block forming a pool of water. This is detrimental to bond. Hence, failure occurs predominantly along the bottom of the joint.

Further evidence to this theory is gained by reference to the bond strengths. The 100 percent flow gives the highest strength at 40 degrees, followed by the 130 percent then the 150 percent. The 100 percent has the least amount of water in it, so the pooling effect on the bottom block was the smallest. The bond was broken to the least extent and so the highest bond strength was obtained. The 150 percent had the greatest volume of water, hence the bond was broken to the greatest extent.

At 20 and 30 degrees, the optimum bond appears to be obtained. This is noted by two factors. These are:

(a) The bond strengths generally seem to peak.

(b) The failure mode is predominantly some combination of failure along the top and bottom of the joint or a degree of failure within the mortar itself.

Both these failure mechanisms show evidence of good bond.

6. CONCLUSION

With reference to the results of testing in this research, conclusions are drawn based on the use of a 10.01 block, 61 percent relative humidity, and the use of a mortar mix of one cement to five sand and 0.005 parts of carboxy methylcellulose.

(a) Mortar flow should be matched to block IRA to optimise bond strength. A high flow should be used with high block IRA and a low flow with low block IRA.

(b) Bond strengths at 40 degrees are significantly less than for lower temperatures.

(c) Low bond strengths at high temperature cannot be directly attributed to temperature effects.

(d) The reason for the low bond strengths at 40 degrees is probably the low block IRA values.

(e) Low block IRA at high temperatures is thought to be due to water vapour effects in the atmosphere.

(f) No one mortar flow will consistently give the highest bond strength over a range of temperatures.

(g) Optimum bond appears to be obtained at 20 and 30 degrees.

(h) Under controlled environment conditions, a mix life of 45 minutes is recommended. This would be greatly reduced under field conditions.

(i) Static load on a mortar joint has no influence on bond strength.

(j) Compressive strength of mortar has no correlation to bond strength.

(k) Carboxy methylcellulose improves mortar water retention.

(l) All values of bond strength obtained when the mix was up to 45 minutes old were in excess of code value of 0.28 MPa.

7. REFERENCES

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TABLE 1

MORTAR PROPERTIES

TEMPERATURE (°C)	FLOW (%)	WATER RETENTION (%)	ENTRAINED AIR (%)	COMPRESSIVE * STRENGTH MEAN (MPa)	CHARACTERISTICS (95%) (MPa)	DENSITY kg/m³
10	100	48.6	11.0	14.2	11.4	2020
	130	55.6	7.0	10.5	9.3	2020
	150	65.6	12.0	11.9	11.4	1970
20	100	84.6	--	7.6	6.7	1900
	130	79.5	--	7.3	6.9	1930
	150	74.0	--	5.9	5.5	1870
30	100	82.6	15.0	8.5	8.1	1950
	130	75.9	14.0	7.1	6.4	1950
	150	87.8	13.0	5.9	4.9	1960
40	100	70.2	14.5	8.5	7.1	1990
	130	75.2	13.0	8.1	7.5	1930
	150	81.0	13.5	5.6	4.9	1980

* COMPRESSIVE STRENGTHS FROM CYLINDER SPECIMENS AND NOT CUBE SPECIMENS AS SPECIFIED IN THE STANDARD.

TABLE 2 - IRA RESULTS FOR BLOCKS

IRA (kg/m³)	10°C	20°C	30°C	40°C
Top face of block	3.38	3.18	3.52	0.73
Bottom face of block	1.88	1.89	2.31	0.50

TABLE 3

BOND STRENGTH RESULTS

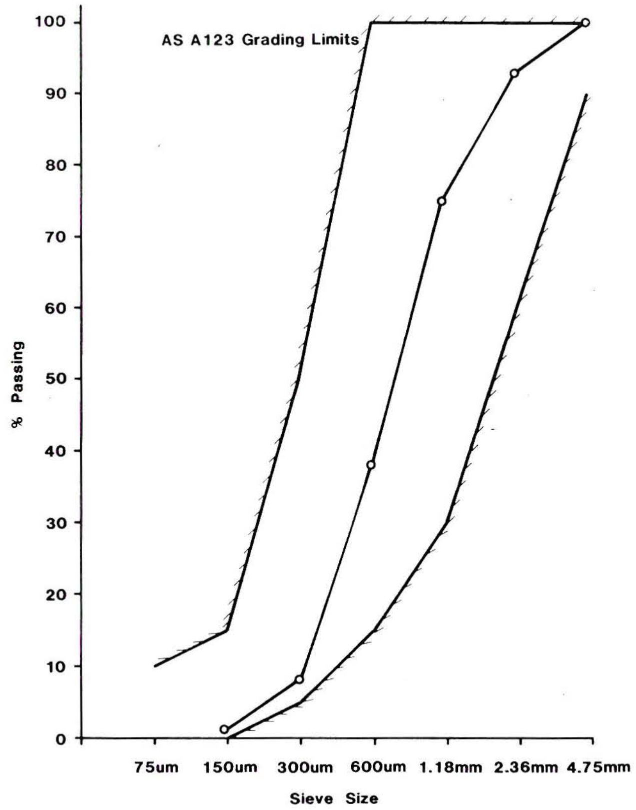
TEMPERATURE (°C)	FLOW (%)	BOND STRENGTH (MPa)				
		CONDITION	NUMBER OF RESULTS	MEAN ST.	S.D.	CHARACTERISTIC ST.
10	100	All results	30	0.42	0.16	0.14
		First 45 mins	18	0.49	0.14	0.24
		Top joint	10	0.48	0.16	0.17
		Middle joint	10	0.37	0.13	0.12
		Bottom joint	10	0.43	0.16	0.12
10	130	All results	30	0.47	0.17	0.18
		First 45 mins	18	0.51	0.15	0.25
		Top joint	10	0.42	0.19	0.05
		Middle joint	10	0.51	0.14	0.24
		Bottom joint	10	0.48	0.18	0.13
10	150	All results	30	0.66	0.16	0.38
		First 45 mins	18	0.73	0.13	0.50
		Top joint	10	0.66	0.20	0.27
		Middle joint	10	0.70	0.16	0.39
		Bottom joint	10	0.61	0.10	0.42
20	100	All results	30	0.50	0.08	0.36
		First 45 mins	18	0.49	0.09	0.33
		Top joint	10	0.52	0.07	0.38
		Middle joint	10	0.52	0.09	0.35
		Bottom joint	10	0.46	0.08	0.31
20	130	All results	30	0.43	0.09	0.27
		First 45 mins	18	0.45	0.09	0.29
		Top joint	10	0.45	0.10	0.26
		Middle joint	10	0.44	0.07	0.30
		Bottom joint	10	0.41	0.12	0.18
20	150	All results	30	0.52	0.08	0.38
		First 45 mins	18	0.54	0.09	0.38
		Top joint	10	0.55	0.06	0.43
		Middle joint	10	0.51	0.08	0.36
		Bottom joint	10	0.51	0.10	0.32

TABLE 4

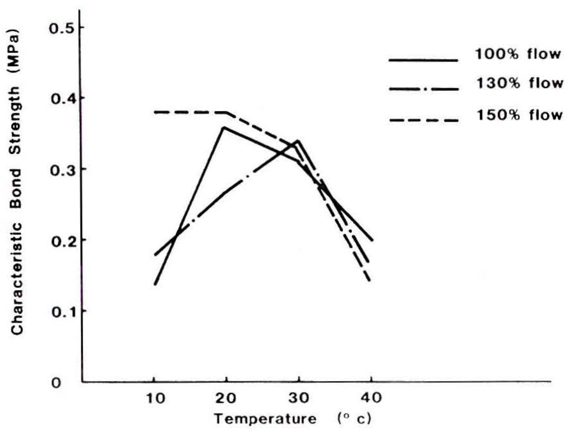
BOND STRENGTH RESULTS

TEMPERATURE (°C)	FLOW (%)	BOND STRENGTH (MPa)				
		CONDITION	NUMBER OF RESULTS	MEAN ST.	S.D.	CHARACTERISTIC ST.
30	100	All results	30	0.55	0.14	0.31
		First 45 mins	18	0.60	0.15	0.33
		Top joint	10	0.55	0.17	0.22
		Middle joint	10	0.60	0.15	0.31
		Bottom joint	10	0.49	0.09	0.32
30	130	All results	30	0.50	0.09	0.34
		First 45 mins	18	0.50	0.11	0.30
		Top joint	10	0.50	0.08	0.35
		Middle joint	10	0.45	0.09	0.28
		Bottom joint	10	0.54	0.09	0.37
30	150	All results	30	0.50	0.10	0.33
		First 45 mins	18	0.49	0.12	0.27
		Top joint	10	0.46	0.14	0.19
		Middle joint	10	0.52	0.07	0.38
		Bottom joint	10	0.52	0.09	0.35
40	100	All results	30	0.39	0.11	0.20
		First 45 mins	18	0.44	0.09	0.28
		Top joint	10	0.36	0.11	0.15
		Middle joint	10	0.41	0.11	0.20
		Bottom joint	10	0.40	0.11	0.19
40	130	All results	30	0.36	0.11	0.17
		First 45 mins	18	0.39	0.12	0.17
		Top joint	10	0.33	0.08	0.18
		Middle joint	10	0.32	0.11	0.11
		Bottom joint	10	0.44	0.12	0.21
40	150	All results	30	0.33	0.11	0.14
		First 45 mins	18	0.39	0.08	0.25
		Top joint	10	0.28	0.10	0.09
		Middle joint	10	0.33	0.09	0.16
		Bottom joint	10	0.40	0.09	0.23

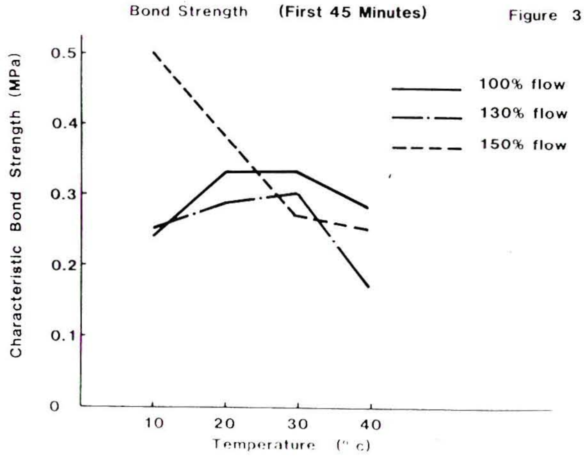
Grading Curve Figure 1



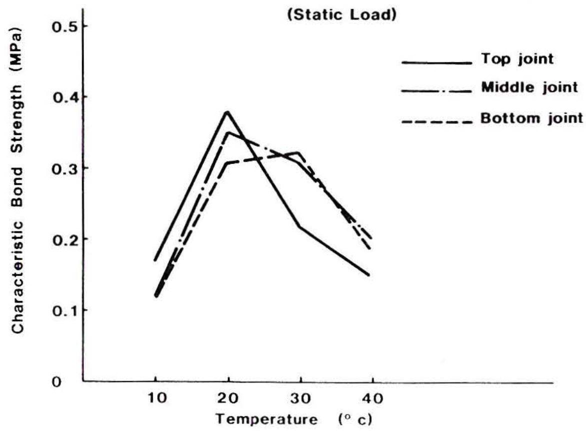
Bond Strength (All Results) Figure 2



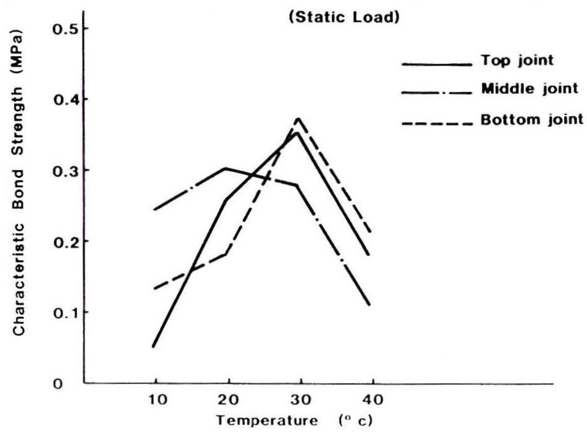
Bond Strength (First 45 Minutes) Figure 3



Bond Strength - 100 Percent Flow Figure 4
(Static Load)



Bond Strength - 130 Percent Flow Figure 5
(Static Load)



Bond Strength - 150 Percent Flow Figure 6
(Static Load)