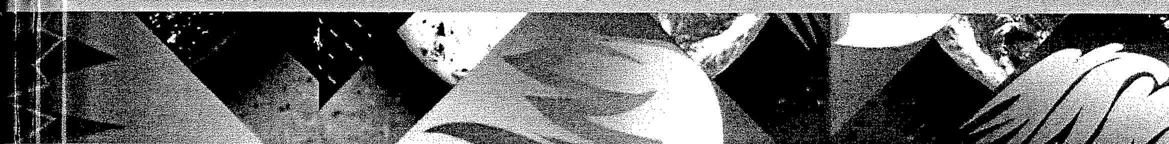
Sustainable Concrete Construction



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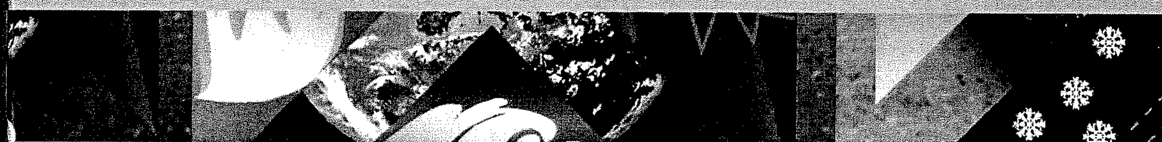
Sustainable Concrete Construction

Concrete is a global material that underwrites commercial well-being and social development. Notwithstanding concrete's uniqueness, it faces challenges from new materials, environmental concerns and economic factors, as well as ever more demanding design requirements. Indeed, the pressure for change and improvement of performance is relentless and necessary.

Sustainable Concrete Construction forms the Proceedings of the three-day International Conference held during the Congress, Challenges of Concrete Construction, 5–11 September 2002, organised by the Concrete Technology Unit, University of Dundee. The Conference deals with such issues as environmental strategies, reuse of waste materials, recycling opportunities, sustainable design and construction, and economics for sustainability.



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- Sustainable concrete construction
- Concrete for extreme conditions
- Composite materials in concrete construction
- Concrete floors and slabs
- Repair, rejuvenation and enhancement of concrete

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PREFACE

Concrete is a global material that underwrites commercial well-being and social development. Notwithstanding concrete's uniqueness, it faces challenges from new materials, environmental concerns and economic factors, as well as ever more demanding design requirements. Indeed, the pressure for change and improvement of performance is relentless and necessary.

The Concrete Technology Unit (CTU) of the University of Dundee organised this Congress to address these issues, continuing its established series of events, namely, Creating with Concrete in 1999, Concrete in the Service of Mankind in 1996, Economic and Durable Concrete Construction Through Excellence in 1993 and Protection of Concrete in 1990.

The event was organised in collaboration with three of the world's most recognised institutions: the Institution of Civil Engineers, the American Concrete Institute and the Japan Society of Civil Engineers. Under the theme of Challenges of Concrete Construction, the Congress consisted of three Seminars: (i) Composite Materials in Concrete Construction, (ii) Concrete Floors and Slabs, (iii) Repair, Rejuvenation and Enhancement of Concrete, and three Conferences: (i) Innovations and Developments in Concrete Materials and Construction, (ii) Sustainable Concrete Construction, (iii) Concrete for Extreme Conditions. In all, a total of 350 papers were presented from 58 countries.

The Opening Addresses were given by Mr Jack McConnell MSP, First Minister of the Scottish Executive, Sir Alan Langlands, Principal and Vice-Chancellor of the University of Dundee, Mr John Letford, Lord Provost, City of Dundee, Professor Adrian Long, Senior Vice-President of the Institution of Civil Engineers, Dr Taketo Uomoto, Director of the Japan Society of Civil Engineers and Dr Terence Holland, President of the American Concrete Institute. The Congress had six Opening and six Closing Papers dealing with the main themes of the Seminars and Conferences. Opening Papers were presented by Professor Gerard Van Erp, University of Southern Queensland, Australia Dr Peter Seidler, Astradur Industrieboden, Germany and Professor Kyosti Tuttii, Skanska Teknik AB, Sweden, Professor Surendra Shah, Northwestern University, USA, Dr Philip Nixon, Building Research Establishment, UK and Mr Hans de Vries, Ministry of Transport, the Netherlands. Closing Papers were presented by Dr Gier Horrigmoe, NORUT Technology Ltd, Norway, Professor Andrew Beeby, University of Leeds, UK, Professor Peter Robery, FaberMaunsell, UK, Professor Heiki Kukko, VTT Building and Transport, Finland, Dr Mette Glavind, Danish Technological Institute, Denmark and Professor Yoshihiro Masuda, Utsunomiya University, Japan. The Congress was closed by Professor Peter Hewlett, Chief Executive of the British Board of Agrément, UK.

The support of 23 International Professional Institutions and 32 Sponsoring Organisations was a major contribution to the success of the Congress. An extensive Trade Fair formed an integral part of the event. The work of the Congress was an immense undertaking and all of those involved are gratefully acknowledged, in particular, the members of the Organising Committee for managing the event from start to finish; members of the International Advisory and National Technical Committees for advising on the selection and reviewing of papers; the Authors and the Chairmen of Technical Sessions for their invaluable contributions to the proceedings.

All of the proceedings have been prepared directly from the camera-ready manuscripts submitted by the authors and editing has been restricted to minor changes where it was considered absolutely necessary.

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THEME 4 TOTAL RECYCLING OPPORTUNITIES

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ROLLER COMPACTED CONCRETE (RCC) – STRENGTH AND PERMEABILITY OF HORIZONTAL JOINTS

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ABSTRACT. Roller compacted concrete is a very dry material consolidated by the use of a powerful external vibratory compaction. It can be defined as concrete of no-slump consistency in its unhardened state that is transported, placed and compacted using earth and rockfill construction equipment. Properties of hardened RCC are similar to those of conventional placed concrete. This material is mainly used in gravity or arch/gravity dams on which RCC construction methodology, by concrete layers, involves a high number and an extensive area of horizontal joints. These joints are the weakest part of RCC in terms of sliding stability and uplift. This study analyses the influence of different parameters on the properties of the joints, namely the influence of cimentitious material content (150-230 Kg/m^3), percentage of fly ash (30-60%), and maturity of concrete. The results obtained show the importance of knowing the performance of the joint versus time elapsed between the compaction of the upper and lower layer.

Keywords: Roller Compacted Concrete (RCC), Layers of RCC, Lift joints, Unconfined shear strength, Tensile strength, Permeability, Maturity, Costs.

J L B Aguiar is a civil engineer and Associated Professor in the Department of Civil Engineering at the University of Minho. His PhD Thesis and research focuses the study of bond properties in the interface between different materials.

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INTRODUCTION

Roller Compacted Concrete for gravity or arch/gravity dams involves a high number of horizontal joints which is the result of the special technique used for compaction of the successive horizontal layers with a very big area in the total volume of the dam. The most common thickness used for compacted layer has been 300 mm which means that we have 3.3 m^2 of joint area each cubic meter of placed concrete [1],[2],[3].

The number of lifts on which treatment could be avoided is a very important economic question. For instance, during the construction of Willow Creek Dam, for a total of 263 lifts placed, only 22 were treated as "cold joints"[1].

The quality of the interface between layers depends on several factors. Some of them are related to the quality of mixture, as [4],[5]:

- gradation of the mixture and maximum size of the aggregates;
- cimentitious materials content;
- setting time of the mixture,

and others are related to the conditions of placement of the RCC, as:

- the temperature of the mixture;
- the time elapsed between the compaction of the lower and upper layer;
- the concrete cure (mainly on the surface)
- the roughness of the surface of the lower layer, for "cold joints";
- energy of compaction;
- time between spreading and initial of compaction;

This work only analyses the influence of the time elapsed between the compaction of the lower and upper layer on the quality of the joint.

This paper describes the laboratory research made during the design of a gravity dam (130 m height above foundation) for evaluation of shear and tensile strength and waterproofing properties of lift joints. The influence of maturity of concrete surface was studied in RCC mixtures made with different cimentitious contents and using the "in situ" available aggregates (granite).

RESEARCH SIGNIFICANCE

The treatment of horizontal joints may represent an important additional cost to dam construction, which could be avoided if a correct evaluation of the mechanical and impervious properties were made before the works starts, taking into account the design specifications and the works schedule.

Two extreme situations can occur on internal horizontal joints [6],[7]:

a) absence of joint – does not exist physical and chemical heterogeneity along the surface, i,e., it occurs a physical inter penetration of paste and aggregates and the hydration of the cimentitious material of both layers proceed without occurrence of interfaces paste-paste;

b) very weak transition zone on the joint - the concrete of the upper layer does not penetrate into the lower layer and low level of hydration bond occurs ("cold joints") [2].

In common practices the quality of the joint is somewhat between these two extremes.

The usual specifications for joint quality does not include the measurements of the significant properties to ensure the accomplishment of the design.

The knowledge of the behaviour of concrete related to maturity is a very important step for better specifications on tender documents

MATERIALS

Components of RCC

Portland Cement (CEM I – 42,5R as specified on EN 197-1);
Siliceous Fly Ash (conforming EN 450);
Set retarder admixture;
Potable water;
Crushed-granitic aggregates .

RCC Mixtures

Nine RCC mixtures were tested (Table 1). The total cimentitious material content were 150Kg/m^3, 190 Kg/m^3, 230 Kg/m^3 respectively for concrete 1, 2 and 3. The PFA content were 30%, 45% and 60% respectively for concrete A, B and C.

Table 1 Mixtures tested - quantities per cubic meter

CONCRETE	A1	A2	A3	B1	B2	B3	C1	C2	C3
Cement, kg/m^3	105	133	161	83	105	126	60	76	92
Fly Ash, kg/m^3	45	57	69	67	85	104	90	114	138
C.A. 19/38 mm, kg/m^3	656	655	631	656	655	631	656	655	631
C.A. 5/19 mm, kg/m^3	492	527	594	497	534	602	503	572	608
Fine Agg., kg/m^3	897	827	750	887	815	734	876	793	719
Water, kg/m^3	134	135	137	134	135	137	134	136	138
Admixture, %pw	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

The gradation of each class of the aggregates and concrete is shown in Figure1.

The consistency of the mixtures were in the range of 15s to 30s VeBe, measured according ASMT C 1170, Method A [8].

The initial setting time of mixture A3 with the highest cement content and lowest percentage of PFA(30%), measured according ASTM C 403 [9], was 7h30m.

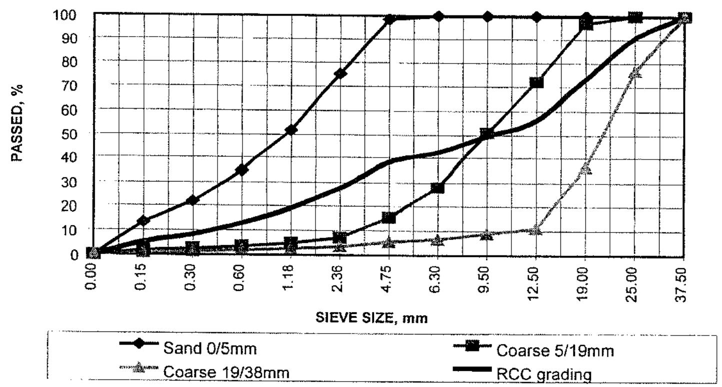

Figure 1 Aggregates granulometry and RCC gradation

Test Programme and Methods

For each RCC mixture samples were prepared in two layers according the procedure described in ASTM C 1176 [10]. The compaction of the upper layer of the unjointed samples was performed immediately after the compaction of the lower layer. The compaction of the upper layer of the jointed samples was made after different periods of time of the end of compaction of the lower layer. The concrete of the two layers were produced from different batches. Table 2 shows the testing programme, including properties measured and procedures of the tests.

Table 2 Testing programme for all mixtures – tests, number of samples and procedures

TESTS	TYPE OF SPEC.	NUMBER. OF SPECIMENS Age 28 d	90 d	365 d	TEST PROCEDURE
Compressive strength (unjointed)	(1)	2	2	2	[11]
Tensile strength (unjointed)	(1)	2	2	2	[12](Figure 2)
Tensile strength (jointed at 3h, 5h, 8h and 12h)	(1)	2	2	2	[12](Figure 2)
Unconfined shear Strength (unjointed)	(2)	2	2	2	[13](Figure 3)
Unconfined shear strength (jointed at 3h, 5h, 8h and 12h)	(2)	2	2	2	[13](Figure3)
Water penetration (unjointed)	(3)	---	2	---	[14] (4)
Water penetration (jointed at 3h, 5h, 8h and 12h)	(3)	---	2	---	

Notes: (1) cylinder specimens ϕ=150mm, h=300mm; (2) cube specimen a=150mm; (3) cube specimen a=200mm. (4) See text below.

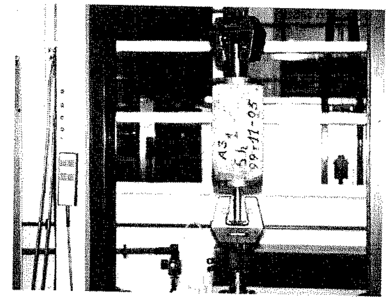

Figure 2 Tensile test set-up

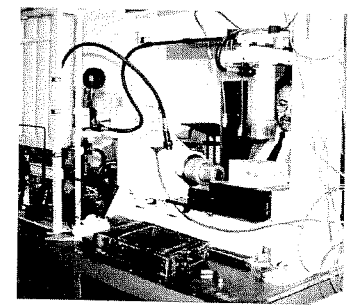

Figure 3 Shear test set-up

The water penetration test was made according reference [8], using a 2.5 bar pressure during 48 hours.

The two specimens moulded for determination of the depth of penetration under water pressure were not measured in the same way. While in the first specimen, the measurement of depth of penetration was made in a perpendicular plane to the joint, in the second specimen the measurement was made in the plane of the joint. The pressure was applied in the direction to the joint. This procedure permits to observe the different paths of the water penetration in the joint itself and in the neighbourhood of the joint. Behind the depth of penetration, it was also measured the saturated area.

RESULTS AND DISCUSSION

Table 3 shows the results of tensile and shear strength and water penetration. Figures 4-6 shows the compressive strength results.

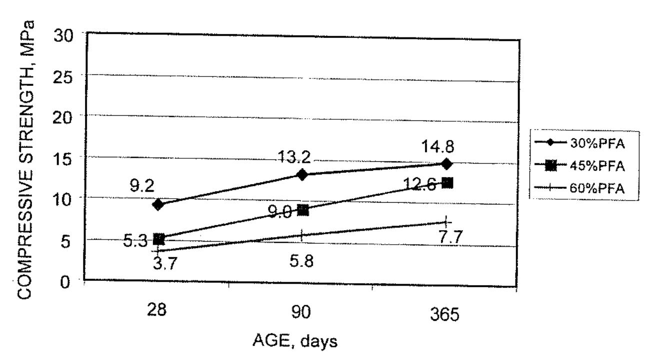

Figure 4 Compressive Strength, Mixes A1, B1, C1

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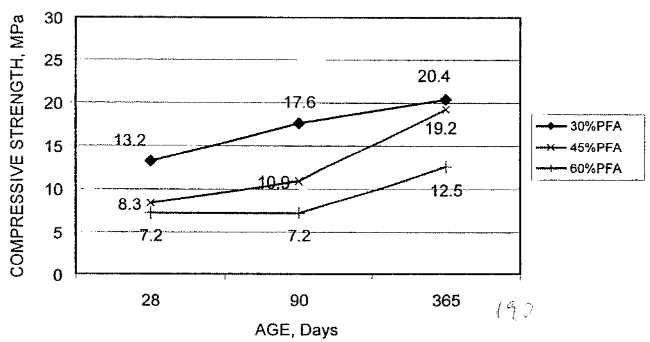

Figure 5 Compressive Strength, Mixes A2,B2,C2

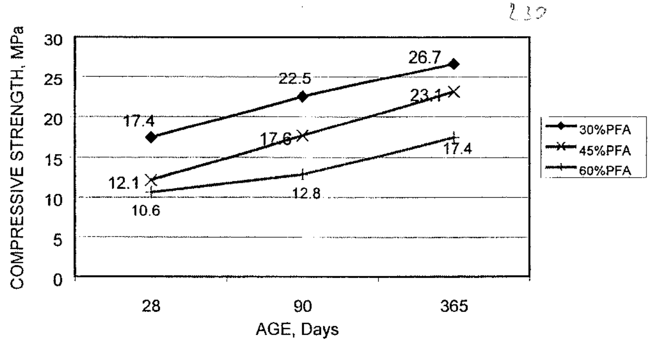

Figure 6 Compressive Strength, Mixes A3,B3,C3

Tensile Strength

Figure 7 shows the jointed tensile strength average values as percentage of the unjointed tensile strength.

The average of the decrease of tensile strength is not very significant until 8h. After this period of time the tensile strength it can be observed a significant drop, which is correlated with the initial setting time of concrete.

The lower values obtained at 3 and 5h, when compared with the unjointed samples, can be attributed to the decrease on the workability of the concrete of the lower layer which difficult the inter penetration of both layers. This can be observed of Figure 8 that shows the failure surface at different maturity for A3 mix, at 0h, 3h and 5h, where it can be seen the loss of roughness with time.

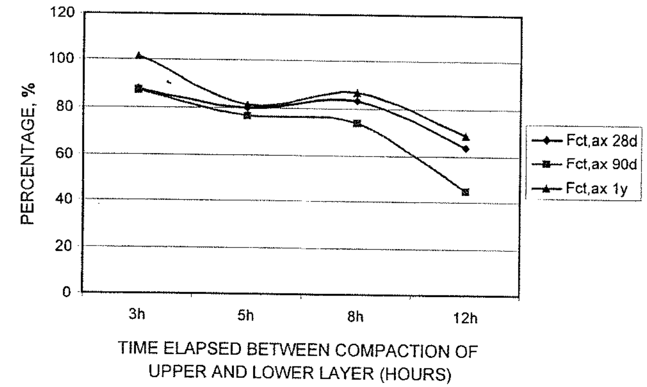

Figure 7 Loss of tensile strength with time between compaction of upper and lower layer

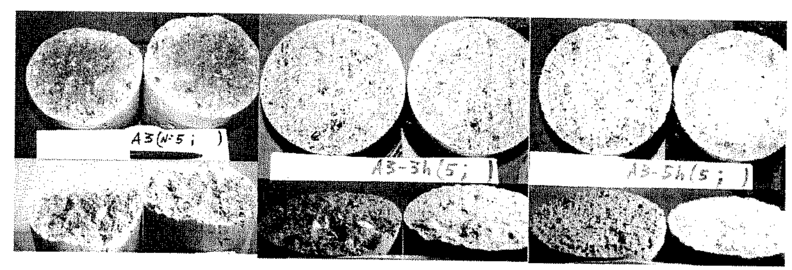

Figure 8 Failure surface at 0h,3h and 5h of A3 sample

Shear Strength

Figure 9 shows the jointed shear strength average values as percentage of the unjointed shear strength.

The values show the same trend that was observed in tensile strength tests. However at 1 year age the decrease is smaller than at other ages. This is probably due to the higher rigidity of the paste which allows different stress distribution on specimens. The applied tangencial force can be supported by a bridging effect which interest a thicker portion of concrete in the neighbourhood of the joint.

Table 3 Tests results (mean of 2 specimens except for water penetration)

MIX	JOINTS Elapsed Time, hours	TENSILE STRENGTH, MPa 28d	90d	365d	SHEAR, STRENGTH MPa 28d	90d	365d	WATER PENETRATION(*) Depth, mm Perp	Paral	Area, cm² Perp	Paral
A1	0	0.77	1.23	1.39	1.36	1.64	1.93	94	92	127	147
	3	0.64	0.59	0.76	1.06	0.92	1.74	110	130	157	250
	5	0.40	0.44	0.29	0.52	0.78	1.26	111	160	154	288
	8	0.45	0.575	0.66	0.88	1.04	1.78	121	152	133	296
	12	0.32	0.475	0.57	0.38	0.68	1.74	141	142	204	284
A2	0	1.12	1.31	1.53	1.67	2.20	2.62	79	65	68	87
	3	0.78	1.19	0.97	1.26	1.70	2.68	117	118	176	212
	5	0.37	0.965	0.29	0.23	1.15	1.81	122	124	173	217
	8	0.98	0.92	1.07	1.20	1.93	2.78	(***)	(***)	(***)	(***)
	12	0.48	0.58	0.52	0.18	0.84	1.94	(***)	(***)	(***)	(***)
A3	0	1.61	1.585	1.89	2.21	2.85	3.68	42	55	36	58
	3	1.32	1.455	1.10	2.88	2.78	3.48	(***)	(***)	(***)	(***)
	5	1.06	1.435	0.50	1.89	2.42	3.45	110	108	182	189
	8	0.93	0.735	0.71	0.88	0.88	2.89	96	89	139	142
	12	0.58	0.35	0.33	0.15	0.91	2.03	142	159	220	318
B1	0	0.63	0.845	0.91	1.08	1.06	1.71	135	142	224	260
	3	0.64	0.77	0.87	0.34	0.67	2.06	(***)	(***)	(***)	(***)
	5	0.64	0.72	0.48	0.37	0.24	1.43	(***)	(***)	(***)	(***)
	8	0.74	0.75	0.66	0.36	0.68	1.14	101	179	152	313
	12	0.65	0.305	0.85	(**)	0.15	1.13	107	109	150	191
B2	0	1.05	1.215	1.57	1.47	1.27	2.81	(***)	64	(***)	74
	3	0.89	1.17	1.21	1.14	1.59	3.13	161	147	300	280
	5	0.84	0.78	1.15	1.16	1.32	2.72	145	140	260	280
	8	0.95	0.795	1.17	0.86	0.85	2.86	182	(***)	320	(***)
	12	0.55	0.305	0.40	0.62	0.13	1.62	(***)	(***)	(***)	(***)
B3	0	1.23	1.515	1.69	1.69	1.59	2.71	74	87	74	123
	3	1.12	1.19	1.76	2.26	2.37	4.23	129	(***)	219	(***)
	5	1.19	1.205	1.62	1.39	1.94	3.17	127	135	222	258
	8	1.13	1.32	1.87	1.25	1.50	3.32	112	113	174	203
	12	0.94	0.9	0.70	0.47	1.44	3.15	150	144	258	365
C1	0	0.46	0.525	0.47	0.32	0.83	1.13	(***)	(***)	(***)	(***)
	3	0.51	0.635	0.63	(')	0.75	1.40	(***)	(***)	(***)	(***)
	5	0.44	0.56	0.50	0.57	0.76	1.11	(***)	(***)	(***)	(***)
	8	0.35	0.39	0.53	0.42	0.69	1.25	(***)	(***)	(***)	(***)
	12	0.39	0.365	0.38	0.30	0.49	0.53	(****)	(****)	(****)	(****)
C2	0	0.69	0.75	0.70	0.79	1.23	2.05	101	(*)	146	(*)
	3	0.42	0.545	1.10	0.78	1.15	2.17	(****)	(****)	(****)	(****)
	5	0.67	0.445	1.13	0.25	0.75	1.50	(****)	(****)	(****)	(****)
	8	0.52	0.575	0.85	0.32	0.34	1.23	(****)	(****)	(****)	(****)
	12	0.54	0.34	0.76	0.11	0.23	1.21	(****)	(****)	(****)	(****)
C3	0	0.89	1.09	0.97	1.17	1.68	2.64	121	140	214	252
	3	0.92	1.01	1.64	1.21	1.51	3.05	(****)	(****)	(****)	(****)
	5	0.85	0.96	1.69	1.13	1.40	2.75	139	(***)	250	(***)
	8	0.83	1.125	1.24	0.93	1.43	2.57	(***)	(***)	(***)	(***)
	12	0.53	0.67	0.99	0.79	0.52	1.99	(***)	(***)	(***)	(***)

Notes : (*) At 90 days (**) failure immediately after the jack is leaned; (***) higher than 200mm;
(****) after 5-6h t the surface of the lateral faces of the specimen was saturated.

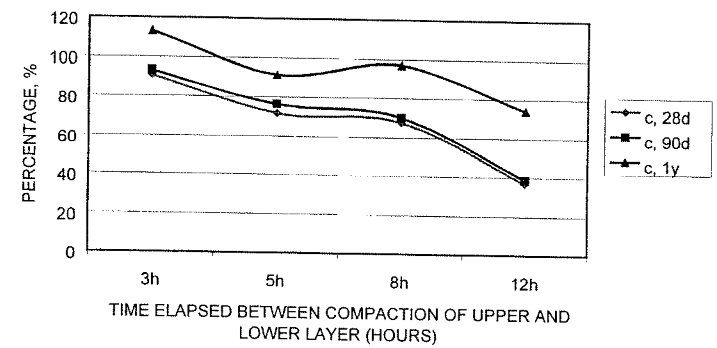

Figure 9 Loss of shear strength with time between compaction of upper and lower layer

Water Penetration

The results of the tests for measuring water penetration under pressure are not plotted because, in several cases as we can see in Table 3, the whole sample were saturated before the end of the test (48h). Anyway if we look the results with possible readings we can see important losses of water-tightness even at 3-h joints, except for A1 mix. This proves that it were very wise to produce samples for 1 year readings. However it seems clear that permeability of the joints increase with the time elapsed and is relatively more sensible to cimentitious content than mechanical properties are.

CONCLUSIONS

The result of this research shows the importance of the previous evaluation on significant properties of the materials during the development of the design. In fact, the design specification would not be satisfied without accurate studies to prevent losses in strength and permeability at joint sections.

As shown in Figure 7 and Figure 9, where it is plotted the medium percentage, for all mixes, the losses of joint strength related to unjointed RCC, we can say that:

- the losses in tensile strength are more significant than in shear strength;
- the reason of the different behaviour between tensile and shear strength could be explain by the influence of roughness and interpenetration of the two layers is more important in shear strength;
- at 1 year age the joint strength after 8 hours of placement of the first layer is still 80% in tensile strength and 95% in shear strength.

Related to the results of water penetration tests, it seems evident the importance of considering an impervious system on the upstream face.

In economic point of view, this results shows that it could be well established the limits for the restrictions on planning RCC production and placement without significant influence on Quality Control parameters.

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