

# Sustainable Concrete Construction



EDITORS

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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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founding Director of the Concrete Technology Unit at the University of Dundee is renowned as a scholar and practitioner in the field of concrete science, technology and construction, as well as for his strong collaboration in research with the construction industry. He was awarded an Honorary Fellowship of the Institute of Concrete Technology in 1994 and appointed an Officer of the Order of the British Empire in 1999 for his services to concrete technology.

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Concrete Technology Unit



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 Thomas Telford

# Sustainable Concrete Construction

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on 9-11 September 2002

Edited by

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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 Tutti, 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, FaberMaunsel, 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.

## CONTENTS

Preface	iii
Introduction	iv
Organising Committee	v
International Advisory Committee	vi
National Technical Committee	viii
Collaborating Institutions	x
Sponsoring Organisations With Exhibition	x
Supporting Institutions	xi
<b>Opening Paper</b>	<b>1</b>
<i>More sustainable construction: the role of concrete</i> P J Nixon, Building Research Establishment, United Kingdom	
<b>THEME 1 ENVIRONMENTAL STRATEGIES</b>	
<b>Keynote Paper</b>	<b>13</b>
<i>Consider the environment - Why and how</i> B L Jensen and M Glavind, Danish Technological Institute, Denmark	
<i>Effects of construction activities on environment</i> Z A Siddiqi, M A Chaudhry and M Ashraf	23
<i>Comparative study of different fly ashes: Characterisation and performances</i> I Torresan, N Magarotto and N Zeminian	33
<i>Communication, coordination and concrete problems</i> P D Novelli	47
<i>Environmental information on concrete</i> J Bijen	57
<i>Implications of the Kyoto Protocol: The introduction of the Climate Change Levy in the UK and its consequential requirements and impacts on the UK cement industry</i> R Fowler	67
<i>Behaviour of cement/plating waste derived products: Unconfined compressive strength and setting time</i> O I Fernandez, P Lopez and A Irabien	77

87	<i>Sustainable development of cement and concrete IT providing a path from research to practice</i> I Kondratova	223	<i>The production of superpozzolan from coal fired utility ash ponds</i> T L Robl and J G Groppo
95	<i>Development of a low energy environmentally friendly cement</i> P Jimenez, S Goni, A Guerrero, M P Lorenzo and A Macias	231	<i>Using recycled brick as concrete aggregate</i> K Jankovic
107	<i>The contribution of organic acids and enriched industrial by-products in energy conservation during cement clinker production</i> V Kasselouri-Rigopoulou and S Antiohos	241	<i>Utilization of CCPs in Europe</i> P Brennan, N Cooke and W vom Berg
	<b>THEME 2 REUSE OF WASTE MATERIALS</b>	253	<i>Cork granules as lightweight aggregate</i> S R Karade, M Inle, K Maher and F Caldiera
	<b>Keyword Paper</b>	263	<i>The effect of Metakaolin additions on strength development in cement mortars</i> S S Potgieter, J H Potgieter and P Napo
117	<i>The role of combustion by-products in sustainable construction materials</i> T Naik, University of Wisconsin, Milwaukee	271	<i>Mining backfill formulations from various cementitious and waste materials</i> J H Potgieter and S S Potgieter
131	<i>The use of cellulose wastes in lightweight concrete: improvement of properties by admixtures</i> R Jaubertie, C Lanos, I Cisse, S Tamban and F Rendell	281	<i>By-products from mineral and metallurgical industries as filler in concrete</i> H Moosberg-Bustnes
139	<i>Hydrated lime pastes containing coal-fly ash and polyaminophenolic additives for the inertization of fly ashes from municipal solid wastes incinerators</i> G Rinaldi and F Medici	291	<i>Recycling of masonry debris as a raw material in the ceramic industry</i> K van Dijk, A L A Fraaij, Ch F Hendriks, E Mulder and J van der Zwan
151	<i>Utilization of converter slag as a concrete admixture</i> Y Umemura and N Tsuyuki	305	<i>Structural lightweight concrete - an environmentally responsible material of construction</i> M N Haque, O Kayali and H Al-Khaiaf
161	<i>Comparative response of SBR latex modified concrete</i> S A Rizwan, K Ahmad and A Hameed	313	<i>The environmental benefits of using PFA in cementitious systems</i> L K A Sear
171	<i>Low water demand binders in road building</i> A M Gridchin, R V Lesovik and V V Strokova	323	<i>Study on the utilisation of melting slag from municipal solid waste as concrete materials</i> M Kitatsujii, T Endo, H Ishida and K Fujii
177	<i>Investigation of the use of waste plastic as an aggregate for lightweight concrete</i> H Koide, M Tomon and T Sasaki	335	<i>Aggregate cement reactions in MWI-bottom ash-based concrete - a petrographical assessment</i> B Laenen, R Dreesen and D Van Rossem
187	<i>Performance of concrete with recycled aggregates</i> A L A Fraaij, H S Pietersen and J de Vries	345	<i>Use of Na and K as inert elements for the long-term leaching assessment of heavy metals from cementitious matrices containing waste material</i> T Van Gerven, V Dutre, D Geysen and C Vandecasteele
199	<i>Dump slags in concretes, solutions and binders</i> B S Batalin and V G Kraft	355	<i>Durability of cement rubber-composites under freeze thaw cycles</i> A Benazzouk and M Queneudec
205	<i>Advantages of simultaneous use of cement kiln dust and blast furnace slag</i> G Bais, E Rakanta, E Sideri, E Chaniotakis and A Papageorgiou	363	<i>Fly ash lightweight aggregates produced by cold bonding for sustainable concrete construction</i> C Videla and P M Martinez
213	<i>A new low-heat sulfate resistant binder for mass concrete, HPC and SCC</i> D Novak and H Sommer		

<i>The hardening and leaching properties of the cementitious matrix and of the concrete with electropositive waste admixture</i> M Gheorghie, D Voimitchi and R Teodorescu	373	<b>THEME 4 TOTAL RECYCLING OPPORTUNITIES</b>	<b>Keynote Paper</b> <i>Total recycling opportunities - tasting the topics for the conference session</i> M Tørring and E Lauritzen, DEMEX Consulting Engineers A/S, Denmark	501
<i>Mechanical properties and durability of concrete made with coarse and fine recycled concrete aggregates</i> S Kenai, F Debieb and L Azzouz	383		<i>A new concrete recycling technique for coarse aggregate regeneration process</i> K Yanagibashi, T Yonezawa, K Arakawa and M Yamada	511
<i>The use of waste materials in aggregate concrete blocks</i> S L Garvin, J P Ridal and C P Hayles	393		<i>The "LAW" process: an innovative waste valorization proposal combined with power production</i> R Ippoliti, M P Contento and F Cioffi	523
<i>Development and performance of cement kiln dust-slag cement</i> M S Konsta-Gdoutos, S P Shah and S Bhattacharja	403		<i>Sustainable use of recycled materials in building construction</i> Ch F Hendriks, J G Voglander and A Fraaij	535
<i>Effect of cement-by-pass-dust on concrete</i> A S Al-Harthi and R Taha	411		<i>Removal of gypsum plaster by the use of microwaves</i> L Gerlach, J Eibl and L Stempniewski	545
<i>Interactions of waste glass cullet in simulated cement pore fluid</i> L J Csetenyi and Z Apagyí	419		<i>A closed material cycle for concrete, as part of an integrated process for the reuse of the total flow of C&amp;D waste</i> E Mulder, J Blaakmeer, L Tamboer and T G Nijland	555
<i>Full scale trials using incinerator bottom ash in cement based products</i> J E Halliday and R K Dhir	429		<i>Shrinkage and creep of recycled concrete interpreted by the porosity of their aggregate</i> J M Gomez-Soberon, J C Gomez-Soberon and L A Gomez-Soberon	563
<b>THEME 3 ENVIRONMENTALLY SENSITIVE CONCRETE CONSTRUCTION</b>			<i>Road concrete from wastes of industry</i> S I Pavlekno	577
<b>Keynote Paper</b> <i>Rethinking sustainable concrete construction</i> P G Goring, John Doyle Construction, United Kingdom	439	<b>THEME 5 DESIGN AND CONSTRUCTION</b>	<b>Keynote Paper</b> <i>Sustainable concrete construction - Issues for developing countries</i> S A Reddi, Gammon India Limited, India	587
<i>Concrete design considering environmental performance</i> K Kawai and T Sugiyama	457		<i>Performance based durability design</i> J Bijen	605
<i>Demountable prefabricated reinforced concrete structure designed for multistorey car parks</i> A Ionescu and T Hodisan	465		<i>Durability field investigation of an abandoned concrete bridge</i> M S Mirza and L Amleh	617
<i>Evaluation of hybrid concrete construction for the UK market</i> J Glass, B Baiche and C Goodchild	475		<i>Safety assessment of constructions made of reinforced concrete considering microcrack formation</i> S V Elizarov and A V Benin	627
<i>Commercial-scale recovery of lightweight block sand from stored coal combustion ash</i> J Groppo and T Robl	485		<i>A delivery system for sustainable concrete construction</i> M E Brander	637
<i>A tailor made road binder for hydraulically bound bases with induced cracks</i> H Sommer	495			

645	<i>Durability of lime stabilised earth blocks</i> A Guettala, H Houari, B Mezghiche and R Chebili	
655	<i>Cement stabilised laterite sub-base material</i> R Jaubertie, C Lanos, I Cisse, N Diouf and F Rendell	
665	<i>Recycling of waste bricks in the fabrication of dune sand concrete</i> L Azzouz, M Bouhicha and S Kenai	
675	<i>Predicting strength properties of fine cementless ash-slag concrete</i> S I Pavlenko, M V Lukhanin and N N Tkachev	
	<b>THEME 6 ECONOMICS FOR SUSTAINABILITY</b>	
	<b>Keynote Paper</b>	
683	<i>Economics, sustainability and concrete</i> D Pocklington, British Cement Association, and J Glass, Oxford Brooks University, United Kingdom	
695	<i>Structural performance of lightweight reinforced beams containing periwinkle shells as coarse aggregate</i> F Falade and F Tella	
703	<i>Assessing concrete technology innovation using value engineering (ACTIVE)</i> J Glass, B Baiche and M Jenks	
711	<i>Properties of a low cost concrete formulated with a desert dune sand and calcareous filler</i> A Bali, M L Benmalek and M Queneudec	
721	<i>Treatment and valorisation of oilfield wastes (cuttings) in civil engineering construction</i> R Boutemeur, N Boutemeur, N Benoumechiara and A Bali	
729	<i>Pulverized coal combustion dry bottom ash for Portland cement concrete rigid pavements</i> N Ghafouri	
739	<i>Behaviour of limestone sand based concrete with variable filler content</i> Z Guemmadi, B Toumi and H Houari	
751	<i>Roller compacted concrete (RCC) - strength and permeability of horizontal joints</i> A Camelo, B Aguiar and B Ribeiro	
761	<i>Teaching a concrete subject in a fluid environment. Innovative methods of teaching civil engineering students about concrete technology and durability in a climate of diminishing funding for universities.</i> L J Lee and R J Wheen	
	<b>Closing Paper</b>	
	<i>Green concrete - a life cycle approach</i> M Glavind and C Munch-Petersen, Danish Technological Institute, Denmark	771
	<b>Late Papers</b>	
	<i>Selection of concrete constituents by electro-hydraulic comminution</i> E Linss and A Müller	787
	<i>Recycling concrete: Towards a holistic approach</i> F P Glasser and N Grant	797
	<i>Properties of Tyre Rubber Ash Mortar</i> N M Al-Akhras and M M Smadi	805
	<b>Congress Closing Paper</b>	
	<i>Concrete: Vade Mecum</i> P C Hewlett, British Board of Agrément, UK	815
	<b>Index of Authors</b>	831
	<b>Subject Index</b>	833



## INDEX OF AUTHORS

Aguilar, B	751-760	Endo, T	323-334
Ahmad, K	161-170	Falade, F	695-702
Al-Akhras	805-814	Fernandez, O I	77-86
Al-Harthy, A S	411-418	Fowler, R	67-76
Al-Khatat, H	305-312	Fraaij, A L A	187-198
Amieh, L	617-626		291-304
Antiohos, S	107-116	Fujii, K	535-544
Apaygi, Z	419-428	Garvin, S L	323-334
Arakawa, K	511-522	Gerlach, L	393-402
Ashraf, M	23-32	Geysen, D	545-554
Azzouz, L	383-392	Ghafoori, N	345-354
Azzouz, L	665-674	Gheorghie, M	729-738
Baiche, B	475-484	Glass, J	373-382
Bali, A	703-710		475-484
	711-720		683-694
	721-728		703-710
Batalin, B S	199-204	Glasser, F P	797-804
Batis, G	205-212	Glavind, M	13-22
Benazzouk, A	355-362		771-786
Benin, A V	627-636	Gomez-Soberon, J C	563-576
Benmalek, M L	711-720	Gomez-Soberon, J M	563-576
Benoumechiara, N	721-728	Gomez-Soberon, L A	563-576
Bhattacharjya, S	403-410	Goni, S	95-106
	57-66	Goodchild, C	475-484
Blaakmeer, J	605-616	Goring, P G	439-456
Bouticha, M	555-562	Grant, N	797-804
Boutemeur, N	665-674	Griidchim, A M	171-176
Boutemeur, R	721-728	Groppio, J G	223-230
Brauder, M E	721-728		485-494
Brennan, P	673-644	Guemmedi, Z	739-750
Caldiera, F	241-252	Guerrero, A	95-106
Camelo, A	253-262	Guettala, A	645-654
Chaniotakis, E	751-760	Halliday, J E	429-438
Chaudhry, M A	205-212	Hamed, A	161-170
Chebili, R	23-32	Haque, M N	305-312
Cioffi, F	645-654	Hayles, C P	393-402
Cisse, I	523-534	Hendriks, Ch F	291-304
	131-138		535-544
Contento, M P	655-664	Hevlett, P C	815-830
Cooke, N	523-534	Hodtsam, T	465-474
Csetenyi, L J	241-252	Houari, H	645-654
De Vries, J	419-428		739-750
Debieb, F	187-198	Ionescu, A	465-474
Dhir, R K	383-392	Ippoliti, R	523-534
Diouf, N	429-438	Irabien, A	253-262
Dreesen, R	655-664	Irlle, M	323-334
Dutre, V	335-344	Ishida, H	231-240
Eibl, J	345-354	Jankovic, K	131-138
Elizarov, S V	545-554	Jaubertine, R	655-664
	627-636		

Jenks, M	703-710	Ribeiro, B	751-760
Jensen, B L	13-22	Ridal, J P	393-402
Jimenez, P	95-106	Rinaldi, G	139-150
Karade, S R	253-262	Rizwan, S A	161-170
Kasseouri-Rigopoulos, V	107-116	Robl, T L	223-230
Kawai, K	437-464		485-494
Kayali, O	305-312	Sasaki, T	177-186
Kenar, S	383-392	Sear, L K A	313-322
	665-674	Shah, S P	403-410
Kitasuji, M	323-334	Siddiqi, Z A	73-82
Koide, H	177-186	Sideri, E	205-212
Kondratova, J	87-94	Smadi, M M	805-814
Konsta-Cidoutos, M S	403-410	Sommer, H	213-222
Kraft, V G	199-204	Sommer, H	493-500
Kraff, V G	335-344	Stempniowski, L	543-554
Laenen, B	131-138	Strokova, V V	171-176
Lamos, C	655-664	Sugiyama, T	457-464
Lauritzen, E	501-510	Taha, R	411-418
Lee, L J	761-770	Tamban, S	131-138
Lesovik, R V	171-176	Tella, F	695-702
Lins, E	787-796	Teodorescu, R	373-382
Lopez, P	77-86	Tomon, M	675-682
Lorenzo, M P	95-106	Torresan, I	177-186
Lukhanin, M V	675-682	Torring, M	33-46
Macias, A	95-106	Toumi, B	501-510
Magarotto, M	33-46	Tsuyuki, N	739-750
Maher, K	253-262	Uemura, Y	151-160
Martinez, P M	363-372	Uemura, Y	151-160
Medici, F	139-150	Van der Zwan, J	291-304
Mezghiche, B	645-654	Van Dijk, K	291-304
Mirza, M S	617-626	Van Gerven, T	345-354
Moosberg-Bustnes, H	281-290	Van Rossem, D	335-344
Mueller, E	787-796	Vandecasteele, C	345-354
Mulder, E	291-304	Videta, C	363-372
	555-562	Voglander, J G	535-544
Munch-Petersen, C	771-786	Vomitchi, D	373-382
Nalc, T	117-130	Vom Berg, W	241-252
Nappo, P	263-270	Wheen, R J	761-770
Nixon, P J	1-12	Yanada, M	511-522
Novak, D	213-222	Yanagibashi, K	511-522
Novelli, P D	47-56	Yonezawa, T	511-522
Papageorgiou, A	205-212		
Pavlenko, S I	577-586	Zemintan, N	33-46
	675-682		
Pietersen, H S	187-198		
Pocklington, D	683-694		
Pogteter, J H	263-270		
	271-280		
Pogteter, S S	263-270		
	271-280		
Queeneufec, M	535-562		
	711-720		
Rakanta, E	205-212		
Reddi, S A	587-604		
Rendell, F	131-138		
Rendell, F	655-664		

# 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 cementitious material content (150-230 Kg/m<sup>3</sup>), 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.

**A M R O Camelo** is civil engineer and responsible of Department of Construction Materials in a design company owned by the electricity utility of Portugal (EDP), specialised on concrete dam construction.

**A C B S Ribeiro** is a civil engineer and Researcher of the National Civil Engineer Laboratory (LNEC) specialised on construction materials. His PhD Thesis focuses the study of mixtures and characteristics of roller compacted concrete applied to dam construction.

## 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<sup>2</sup> 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]:

- 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;

- 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<sup>3</sup>, 190 Kg/m<sup>3</sup>, 230 Kg/m<sup>3</sup> 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 <sup>3</sup>	105	133	161	83	105	126	60	76	92
Fly Ash, kg/m <sup>3</sup>	45	57	69	67	85	104	90	114	138
C.A. 19/38 mm, kg/m <sup>3</sup>	656	655	631	656	655	631	656	655	631
C.A. 5/19 mm, kg/m <sup>3</sup>	492	527	594	497	534	602	503	572	608
Fine Agg., kg/m <sup>3</sup>	897	827	750	887	815	734	876	793	719
Water, kg/m <sup>3</sup>	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 Figure 1.

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.

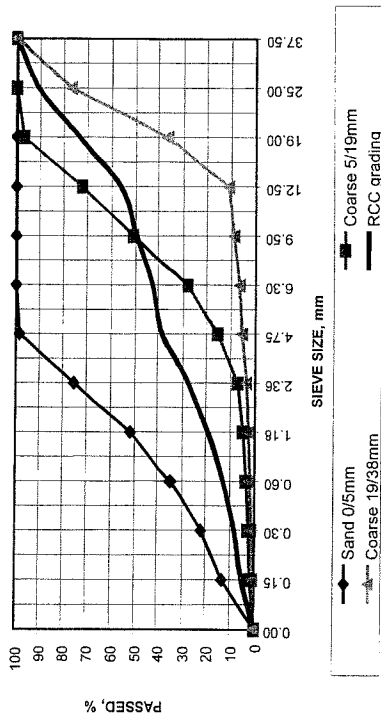


Figure 1 Aggregates granulometry and RCC gradation

**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	TEST PROCEDURE		
			Age	28 d	90 d
Compressive strength (unjointed)	( <sup>1</sup> )	2	2	2	[11]
Tensile strength (unjointed)	( <sup>1</sup> )	2	2	2	[12](Figure 2)
Tensile strength (jointed at 3h, 5h, 8h and 12h)	( <sup>1</sup> )	2	2	2	[12](Figure 2)
Unconfined shear strength (unjointed)	( <sup>2</sup> )	2	2	2	[13](Figure 3)
Unconfined shear strength (jointed at 3h, 5h, 8h and 12h)	( <sup>2</sup> )	2	2	2	[13](Figure 3)
Water penetration (unjointed)	( <sup>3</sup> )	---	2	---	[14] ( <sup>4</sup> )
Water penetration (jointed at 3h, 5h, 8h and 12h)	( <sup>3</sup> )	---	2	---	---

Notes: (<sup>1</sup>) cylinder specimens  $\phi=150\text{mm}$ ,  $h=300\text{mm}$ ; (<sup>2</sup>) cube specimens  $a=200\text{mm}$ ; (<sup>3</sup>) cube specimen  $a=150\text{mm}$ ; (<sup>4</sup>) See text below.

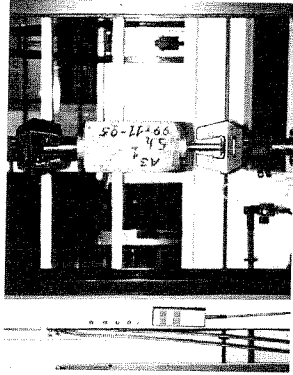


Figure 2 Tensile test set-up

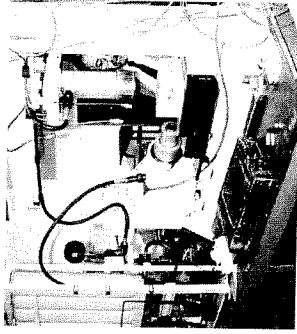


Figure 3 Shear test set-up

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.

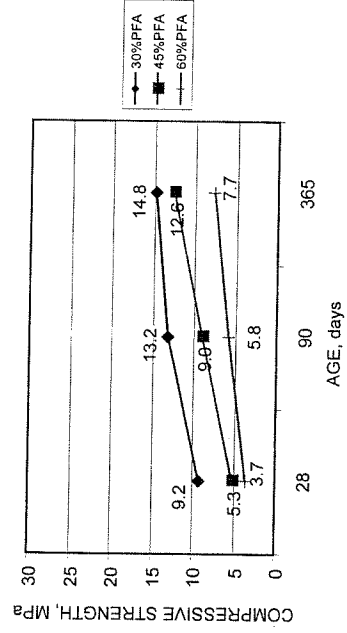


Figure 4 Compressive Strength, Mixes A1, B1, C1

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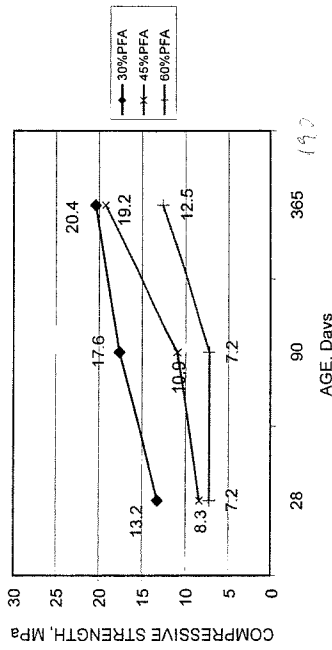


Figure 5 Compressive Strength, Mixes A2, B2, C2

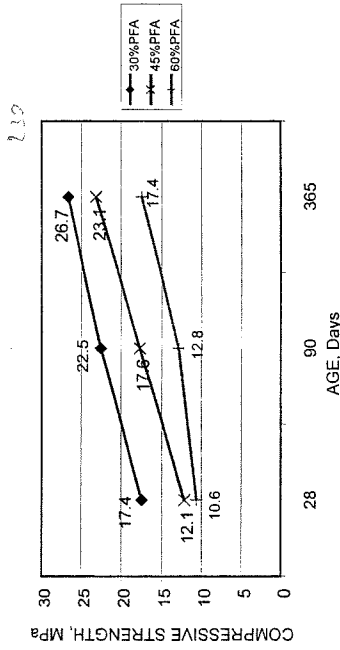


Figure 6 Compressive Strength, Mixes A3, B3, C3

**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.

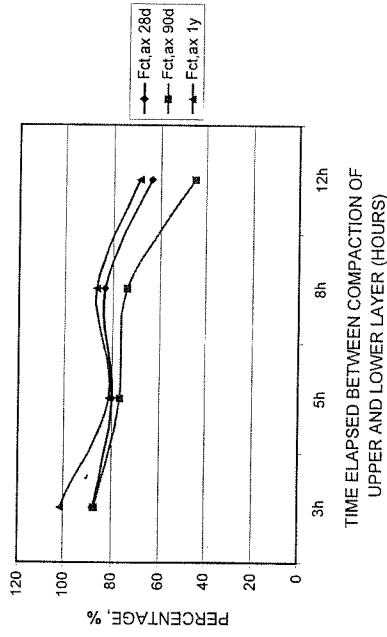


Figure 7 Loss of tensile strength with time between compaction of upper and lower layer

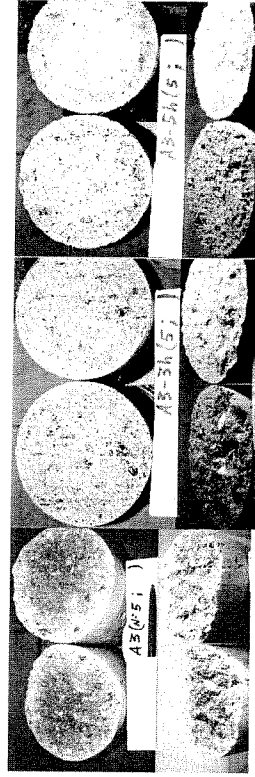


Figure 8 Failure surface at 0h, 3h and 5h of A3 sample

**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 tangential 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	TENSILE STRENGTH, MPa		SHEAR STRENGTH, MPa		WATER PENETRATION(*)					
		Elapsed Time, hours		MPa		Depth, mm		Area, cm <sup>2</sup>			
		28d	90d	365d	28d	90d	365d	Perp	Paral	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
A2	0	0.32	0.475	0.57	0.38	0.68	1.74	141	142	204	284
	3	1.12	1.31	1.53	1.67	2.20	2.62	79	65	68	87
	5	0.78	1.19	0.97	1.26	1.70	2.68	117	118	176	212
	8	0.37	0.965	0.29	0.23	1.15	1.81	122	124	173	217
A3	0	0.98	0.92	1.07	1.20	1.93	2.78	(***)	(***)	(***)	(***)
	3	0.48	0.58	0.52	0.18	0.84	1.94	(***)	(***)	(***)	(***)
	5	1.61	1.585	1.89	2.21	2.85	3.68	42	55	36	58
	8	1.32	1.455	1.10	2.88	2.78	3.48	(***)	(***)	(***)	(***)
B1	0	1.06	1.435	0.50	1.89	2.42	3.45	110	108	182	189
	3	0.93	0.735	0.71	0.88	0.88	2.89	96	89	139	142
	5	0.63	0.845	0.91	1.08	1.06	1.71	135	142	224	260
	8	0.64	0.77	0.87	0.34	0.67	2.06	(***)	(***)	(***)	(***)
B2	0	0.64	0.72	0.48	0.37	0.24	1.43	(***)	(***)	(***)	(***)
	3	0.74	0.75	0.66	0.36	0.68	1.14	101	179	152	313
	5	0.65	0.305	0.85	(**)	0.15	1.13	107	109	150	191
	8	1.05	1.215	1.57	1.47	1.27	2.81	(***)	64	(***)	74
B3	0	0.89	1.17	1.21	1.14	1.59	3.13	161	147	300	280
	3	0.84	0.78	1.15	1.16	1.32	2.72	145	140	260	280
	5	0.95	0.795	1.17	0.86	0.85	2.86	182	(***)	320	(***)
	8	0.55	0.305	0.40	0.62	0.13	1.62	(***)	(***)	(***)	(***)
C1	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
C2	0	0.94	0.9	0.70	0.47	1.44	3.15	150	144	258	365
	3	0.46	0.525	0.47	0.32	0.83	1.13	(***)	(***)	(***)	(***)
	5	0.51	0.635	0.63	( <sup>1</sup> )	0.75	1.40	(***)	(***)	(***)	(***)
	8	0.44	0.56	0.50	0.57	0.76	1.11	(***)	(***)	(***)	(***)
C3	0	0.35	0.39	0.53	0.42	0.69	1.25	(***)	(***)	(***)	(***)
	3	0.39	0.365	0.38	0.30	0.49	0.53	(***)	(***)	(***)	(***)
	5	0.69	0.75	0.70	0.79	1.23	2.05	101	(*)/146	146	(*)/146
	8	0.42	0.545	1.10	0.78	1.15	2.17	(***)	(***)	(***)	(***)
C3	0	0.67	0.445	1.13	0.25	0.75	1.50	(***)	(***)	(***)	(***)
	3	0.52	0.575	0.85	0.32	0.34	1.23	(***)	(***)	(***)	(***)
	5	0.54	0.34	0.76	0.11	0.23	1.21	(***)	(***)	(***)	(***)
	8	0.89	1.09	0.97	1.17	1.68	2.64	121	140	214	252
C3	0	0.92	1.01	1.64	1.21	1.51	3.05	(***)	(***)	(***)	(***)
	3	0.85	0.96	1.69	1.13	1.40	2.75	139	(***)	250	(***)
	5	0.83	1.125	1.24	0.93	1.43	2.57	(***)	(***)	(***)	(***)
	8	0.53	0.67	0.99	0.79	0.52	1.99	(***)	(***)	(***)	(***)

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

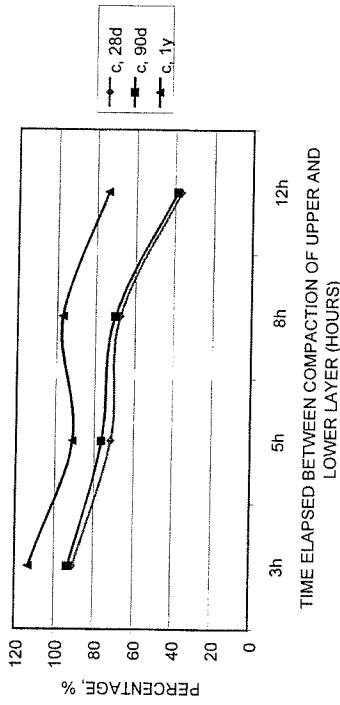


Figure 9 Loss of shear strength with time between compaction of upper and lower layer

### 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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