INTEGRATION, COMPATIBILITY, AND STABILITY OF CERAMIC AND CEMENTING MATERIALS IN BUILDING AND CIVIL WORKS

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ABSTRACT

In view of the new CSIC Strategic Plan for the 2010-13 period, the emerging line of research recently approved on the integration of ceramic and cementing materials into Building and Civil Works is outlined and discussed, taking into consideration both groups of materials and products and their own characteristics, which must act jointly in specific functions. All these components are based on materials with specific features that must interact for a joint function (materials for flooring, façade cladding, and roofing, and other materials that are basically cementing, which act as bonding, support or substrate for these). Given the experience gained in previous years by the two research groups that support this line, the following aspects will be considered:

a) Ceramics and glassy materials with uses in construction. Research will be conducted into all stages of their production cycles (processing, characterisation, properties), placing special emphasis on their integration into construction and civil works, in such a manner that they are not considered as independent materials, but rather as materials that, together with others, form part of an integrated system, which may be façades (traditional, of brick walls, structural, ventilated…), flooring, cladding, or roofs.

At this point in time it is very important to conduct research into specific innovative functions (functional) and new installation techniques (mortar-free paving), in response to social demand, and in compliance with the requirements of

the Spanish Construction Law, LOE (Ley de Ordenacion) and the Technical Building Code (CTE) that develops it, as well as using the knowledge generated in the DIT (National Technical Standards) to establish a "body of doctrine" for integrating ceramic and cementing materials to perform specific functions.

b) In the same way, cementing materials or materials with a cement matrix in all their forms, together or independently, in coatings, substrates, bases, joins, matrixes, agglomerates, structures, etc…, will be researched in terms of their interaction with respect to materials of another nature (ceramics, rocks, minerals, RCDs, steels, and even organic materials). Therefore, research into new procedures and compositional design will enable better integration with ceramic materials and steel or other materials for greater durability.

In consequence, over the years to come this line of research will be conducted into the integration, compatibility, and physico-chemical and mechanical stability of both types of materials, and even those of other types that could be used in construction systems, with respect to traditional existing options or to those originating from earlier periods, and to new materials with innovative benefits: nanomaterials.

1. INTRODUCTION

Words are our means of expression and communication, so they are very important in all areas of life and even more so in Science and Technology where their use involves concepts and ideas with significant theoretical and practical repercussions. This is the case of the word used in the title of this communication for QUALICER 2010. What does the word "integration", applied to ceramic materials and their cementitious adhesives for use in Building Construction Systems, mean in this case and in the context of the New CSIC (Scientific Research Council) Plan, and specifically the IETcc (Institute of Construction Sciences) Plan? This paper seeks to answer this question, and to draw conclusions regarding what all this means to the ceramic floor and wall tile production sector.

In fact, this new QUALICER 10 has been defined as the INTERACTION congress, a word very close to INTEGRATION, both being related to INTERRELATION, so that this communication is in line with a topic that has been of concern to the ceramic floor and wall tile industry in relation to Architecture and Public Works (see communications from previous congresses on Ceramic Tile Quality, www.qualicer.com).

In this case, INTEGRATION is contemplated from two points of view:

a) EXTRINSIC INTEGRATION, as incorporation of ceramic and glassy materials in Construction Systems, and

b) INTRINSIC INTEGRATION, as behavioural interrelation among the glassy

and ceramic materials when applied in constructions and the media used as adhesives or binders (cement materials: brick mortars and cements or cementitious adhesives) or any other fixing or attaching method.

For years now, the industrial and commercial sectors have been greatly concerned about the installation of ceramic materials, defining protocols and procedures for optimal cladding application on building surfaces, and conducting research not only into the problems originating from deficient installation of these materials, but going further and proposing INNOVATIONS for the installation of ceramic materials in Construction Systems. For years now, the industrial sector has been concerned that ceramic products should be installed according to good practices, and has made great efforts to collaborate with training for tile fitters, and especially with manufacturers of mortars, cementitious adhesives, and all types of cement matrix products to assure adequate, optimum characteristics of the ceramic material and that problems originating from installation and the life cycle of the material should not arise, given that they considerably harm the prestige and sales of ceramic materials in the construction sector.

In this context there have been three main trends in recent years:

1) Development of the uses of ceramic materials in Building and Civil Works, enabling their use for purposes other than simply for flooring and internal cladding by architects, specifications writers, developers, etc, as has been the case to date.
2) Improved installation procedures and standards, and an understanding of interactions between ceramic materials and new, varied cementing materials (mortars, adhesive mortars and cements, in some cases with concrete, etc), given that during the last few years infinite variations of both types of product have proliferated, giving rise to new problems due to the lack of genuine research studying the interactions among the product families.
3) At the same time, given that it is now commonly accepted that the thermal behaviour of buildings needs to be optimised to contribute to reducing CO2 emissions, for several years, the outside walls of buildings have been fitted with curtain walls, consisting of glass or thin natural stone panels, etc, and which have extended the possibilities for use of ceramic-type panels, especially those made of porcelain tile. At the same time, several centuries after losing their niche on façades and to recover tradition and conquer new markets, new architectural challenges and the need to extend the areas where ceramic tiles can be applied, a vigorous movement is growing throughout the sector to produce these construction materials to win back the façade market and find innovative fields of application for these materials, thus providing added value for ceramic tiles and giving an economic and technical boost to the sector.

Therefore, in response to the demands of the ceramic sector, a line of research has been proposed that covers the topics of "inter-relation or integration" of ceramic materials with cementing materials in the Strategic Plan for the coming 2010-13 period for R&D+i activity of the Instituto de Ciencias de la Construcción Eduardo Torroja (Construction Sciences Institute) of the Agencia Nacional de Investigación Espanola (Spanish National Research Agency): Consejo Superior de Investigaciones Científicas (Spanish Council for Scientific Research - IETcc, CSIC).

2. HISTORY OF RESEARCH INTO GLASSY AND CERAMIC MATERIALS IN THE INSTITUTO TORROJA, IETCC OF THE SCIC

The Instituto de Ciencias de la Construcción Eduardo Torroja (IETcc, CSIC), throughout its already long history and since its foundation, has conducted research and made scientific and technical contributions in the field of ceramics and glasses. It was one of the founder organisations of the current Spanish Ceramic and Glass Society (SECV). Francisco Arredondo y Verdú played an important role in the foundation and, with a PhD in Road Engineering, he was director of the centre between 1954 and 1970. During the last 15 years this line of research has been strengthened by the creation of the Glassy and Ceramic Materials Group. Rincón et al. (BSECV 2005), reviewed the relationship between this centre and these materials, recalling the most outstanding investigators and publications in this field. An analysis was then made of the current situation and the R&D+i perspectives of glassy and ceramic construction materials, placing highlighting their application in ventilated and conventional façades, and the invigorating effects of scientific research that involves the technical challenge of applying ceramic tiles not only to this type of façades, but also in achieving the extended use of ceramic tiles in Architecture and Civil works that the commercial and business sectors are so keen to achieve. In earlier years, experience in glassy and ceramic materials has also been contributed within the CSIC Network specialising in Historical and Architectural Heritage with contributions as members of this Network and this can be seen in the list of publications from those years.

Therefore, from a strategic point of view, this line, which will consider the integration, interaction and stability of both ceramic and cementing materials, will be **new** or **emerging** in the CSIC, bringing together scientists established in ceramic and cementing materials researches directed by Jesús Ma. Rincón and Rafael Talero, specialists in glassy, ceramic and cementing materials, respectively. The idea is, therefore, to investigate the ceramic and cementing materials integrated in buildings and civil works, from the point of view of their specific functions. All these components are based on materials with specific features that must interact for a joint function (materials for flooring, façade cladding, roofing and other materials that are basically cementing that bind, support or act as substrates for these).

Additionally, there is still a continuing demand for collaboration in Heritage Restoration topics and active cooperation within the PHAC Network in the CSIC, so

this experience in ceramic and glassy materials (and now also cementing materials) and their components will be made available for as long as it is required by sector industries.

3. PERSPECTIVES

As a consequence, this new line of research will study the integration, compatibility and physico-chemical and mechanical stability of existing traditional materials or those from earlier eras, together with new materials with innovative characteristics. For this purpose it has experience in the Construction Systems Department, which was founded three years ago in the IETcc, CSIC with the aim of bringing together the efforts of construction materials physicists and chemists with those of architects and engineers so that through their shared "know-how" they could design (in terms of chemical and microstructural composition and process methods) product prototypes with specific functions in old, current and future Building and Civil Works projects. It is also intended to investigate the behaviour of the INTERFACES among glassy, ceramic and cement materials to optimise their behaviour when INTEGRATED in Construction Systems in Building and Public or Civil Works.

It is a question, therefore, of meeting the constant demands from the ceramic sector and from society, by giving a **new strategic focus to research into ceramic and cementing materials in the IETcc**, making use of the experience of two established scientific groups in these materials (from both the scientific and technological points of view) and in their prior experience with traditional materials requiring rehabilitation or restoration.

Lastly, we would point out that it has a **basic laboratory for the research of ceramic, glassy and cementing materials, which was created in 1994** in the IETcc, which it has been implementing and accessorising over the years (with own funds generated by contracts and projects). It wished to further strengthen this laboratory, as stated in the corresponding section of the Strategic Plan 2010-2013.

At the moment, four doctoral theses are being carried out into this topic (two with an engineering profile and the other with a specialised chemical materials profile), and two further theses are being co-supervised (one with the University of Castile-La Mancha and the other with the University of Cohahuila, Mexico) to guarantee the generational renewal in this line and the spreading of the knowledge generated over the years. Two new young doctors have recently joined the Glassy and Ceramic Materials Group under the JAE Plan (CSIC Study Extension Board), which supports activities carried out as part of this line of research. A new pre-PhD investigator is also starting work on new glass-ceramic-type materials in a Ministry of Science and Innovation project in collaboration with the Instituto de Tecnología Cerámica (Institute of Ceramic Technology - ITC) of the Universidad Jaume I de

Castellón. Therefore, this line of innovative is considered to be of scientific and technical interest, and to have social repercussions for the strategy presented for the 2010-2013 period, because it includes training and activities to spread knowledge on the topic of integration of ceramic materials in constructions.

To prepare this Strategic Plan in the aforementioned new line of research, between February and May this year a DAFO analysis was conducted, from which we identified the strengths, weaknesses, opportunities and selective advantages, which are:

3.1. Strengths.

- Traditional research into glassy and ceramic materials in construction since the founding of the IETcc, meaning that the IETcc was a very active participant in the foundation of the SECV, which will be celebrating the 50th anniversary of its foundation next year.
- It has worked unceasingly since 1994, having implemented a laboratory specifically equipped to meet the demands of the industrial sector and the need for research almost 15 years ago.
- Specialised knowledge of ceramics and glassy materials in general, and more specific knowledge of their application in Architecture and Civil Works with know-how developed over the years.
- Extensive consolidated knowledge of the ceramic floor and wall tile sector (especially the Castellón cluster), and knowledge of clay product manufacturing and environmental industries specialising in industrial waste treatment and recycling.
- Proven experience and international prestige (h rating defining the scientific ranking of the research team members: Jesús Ma. Rincón, h = 15 and Maximina Romero, h = 13) in internationally renowned publications with extensive contact and collaborations with research centres in Europe and Latin American.
- Specialised knowledge of cementing materials, their additives and durability, and more specifically those applicable in Architecture and Civil Works, with the know-how developed throughout the years by the mortar group for this new line of research.
- Extensive established contacts with the industrial cement, concrete, mortar and prefabrication sector.
- The team's capacity to resolve scientific and technical problems, in the dual areas of building and civil works, which they do efficiently in terms of quality, time and economic cost. In other words, in spite of the precarious means, the "Quality/Economic Cost" parameter of the team.
- The investigators involved in this line have a strong, marked scientific-technical profile, which enables them to understand the materials, their mechanisms of interaction and their long-term stability.

3.2. Opportunities.

- The proximity of the IETcc to the Construction sector offers this new line of research the opportunity to investigate materials with a view to their application in real works: Façades of all types, new partitioning, new design systems, advice on pathologies, selection and research of materials for energy saving, use of recycled materials in Building and Public Works, etc…
- Because a member of the group represents us in the ICG (International Commission of Glass), specifically in the TC05: Technical Vitrification Committee, we have the opportunity to promote glassy and ceramic materials in innovative applications and in sustainable construction. We are also a founder member and we are represented at the Institute of Resource Sustainability (ISR-Cer).
- Real opportunities to collaborate with sector associations that have always received attention from the IETcc, CSIC. We also collaborate actively with the Valencia trade fair, CEVISAMA, where IETcc has been represented on a consistent basis for more than 15 years.
- The consolidation of the remaining researchers integrated in this sub-line, specialised in ceramic materials in addition to our specialisation in cement materials, is certainly having a synergic effect on our increased integration in the "Constructive Systems in Building" line.

Additional advantages are the cooperative activities and current projects of the components of this line, which are:

Institute of Ceramic Technology (ITC) of the Universidad Jaume I de Castellón; and with universities such as the UJI itself and the Carlos III de Madrid, Autónoma de Madrid, Politécnica de Madrid (Higher Architectural Studies), Cantrabria, Castile-La Mancha and Extremadura Universities, synergising activities according to the respective specialist areas of the departments involved in the cooperation projects.

With regard to the objectives sought, set out below is a summary of the most significant, which are included in the aforementioned PE2010-13:

General qualitative.

- Consolidate this line within the IETcc, which has arisen as a result of demand from industry and society, by improving the **individual performance of materials, and once they are integrated investigating ways of optimising their compatibility**. Guarantee scientific and technical excellence, knowledge and applications developed.

Specific qualitative.

- Introduce research into innovative products and processes for the development of systems based on ceramic materials and innovative cement materials, including geopolymer-type cements, ensuring the compatibility of their components.

- Maintain and increase the "body of doctrine" in the approach to knowledge and methodologies for these materials.

Scientific objectives.

- Thermal treatments and vitrification by microwave ovens.
- Develop new, non-traditional methods of forming ceramic and glassy products (injection moulding, slip casting, etc.).
- Development of low-temperature ceramic and glassy products (Kyoto commitment) or which lower atmospheric emissions.
- Develop new frits for glazes with improved features and specific functions.
- Investigate the evolution of the mullite phase, essential to the development of new porcelain stoneware materials, through TEM and CBED.
- Study interfaces and evaluate the physico-chemical compatibility of ceramic materials and cementing materials using non-destructive techniques (which will also be extended to systems manufactured using any of these materials and others existing).
- Conduct studies and researches to ensure the adequate durability of materials, including pre-regulatory studies for developing and drafting new regulations, new codes and/or good practices.
- Develop new cementing materials proportioning methods, including alternative materials to existing adhesive cements and mortars (additives, polymers, resins, inorganic fillers, etc.), to optimise their integration with ceramic materials that have now reached their market share peak, such as porcelain tile.

Set out below is a summary of the trends expected to be the most innovative both in ceramic tiles and cementing materials, and which have an impact on their integration. A table is also included showing possible researches that could be undertaken immediately.

MATERIALS	SPECIFIC PRODUCTS
Single-fired stoneware	a) Glass-ceramic-type glazes with alternative materials and manufacturing using prepared industrial waste. b) Functions supported by special properties. c) Large format and special pieces .
Porcelain tile	a) Modified porcelain stoneware (other fluxes and/or inclusion of previously prepared waste). b) Thick glaze coatings. c) Large formats and special pieces.
Glass-ceramic stoneware based on sintering / crystallisation	a) Large grain and fine grain. b) From industrial and/or demolition waste.
Glass mosaic (stoneware tesserae)	a) Glass-ceramic stoneware tesserae. b) Incorporation of waste.

Table 1. Innovative trends in coming years.

MATERIAL	SPECIFIC PRODUCT	REQUIREMENTS
Masonry mortars	a) Cement mortars	Durability
		Leaching attack of Portlandite [$Ca(OH)_2$] through very pure waters
		Acid water attack
		Attack by carbonic anhydride dissolved in natural waters [$CO_2(aq)$]
		Carbonation or attack by carbon dioxide, $CO_2(g)$, of the air
	b) Cement mortars and aerated lime	Sulphate ion attack [SO_4^{2-}]
		Chloride ion attach [Cl^-]
		Seawater attack [SO_4^{2-} and Cl^- ions],
		Attack by aggregate-alkali or alkali-aggregate reaction
		"Aluminosis" of the calcium aluminate cement
	c) Cement mortars and hydraulic lime	Freeze-thaw attack
		Attack by fluxing salts
		Abrasion or cavitation processes
		Compression strength
		According to the mortar proportioning
Adhesive mortars	a) Fast-curing cementitious adhesives	**Adhesion (mortar-single fired tile/ porcelain tile/glass-ceramic/ stoneware tesserae)**
		Initial adhesion
		Adhesion after immersion in water
	a) Slow-curing cementitious adhesives	Curing after heat ageing
		Adhesion after freeze-thaw cycles
		Slipping according to CTE (mortar-single fired tile/porcelain tile/glass-ceramic/stoneware tesserae tile)

Table 2. Joint compatibility with cementing materials.

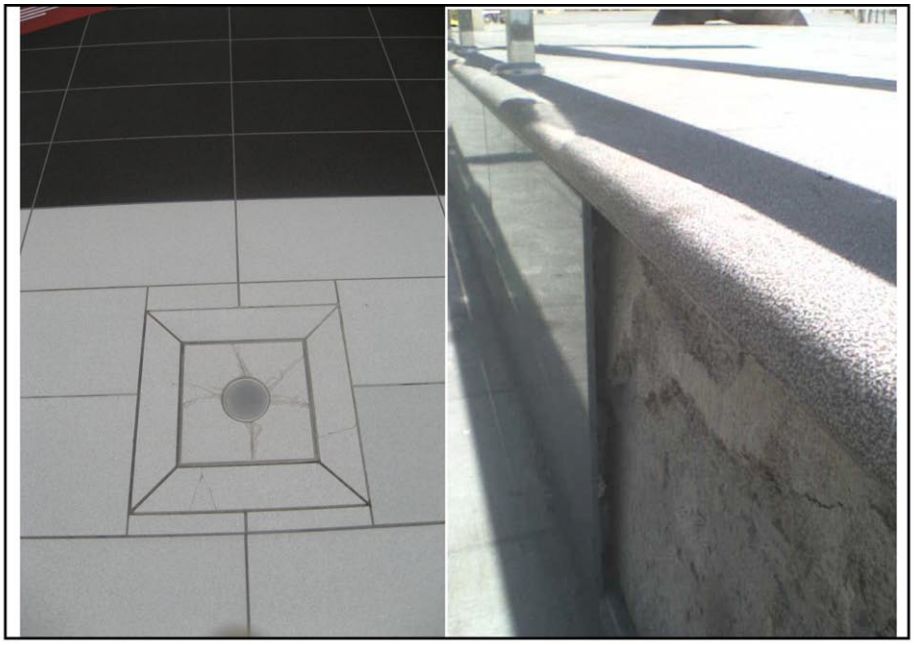
The training objectives are the usual ones, and have been maintained over recent years, which include: Training grants and pre-and post-graduate students on work placements, PhD theses (national and foreign PhD students), tutorship of international and national visitors, PhD and monographic courses aimed at the industry or provided according to their needs. Lastly, the aforementioned PE2010-13 has established specific technology transference objectives, and given the public nature of the State Agency CSIC, objectives for scientific and technical publication are established as one of its priorities in a society where the knowledge generated will have logical repercussions. Internationalisation is another of the priorities of this line, which the CSIC has defined as a priority for the PE2010-13.

With regard to general strategy, the purchase of new equipment and other organisational strategies are planned, such as strengthening ties for cooperating with the UPM, through the proposed implementation of an Associated Unit of the CSIC with the Higher School of Technical Architecture of Madrid and establishing collaborative points with the Professors of Ceramics sponsored by the sector in different university centres.

The following tables show some of the trends foreseen for the coming years, into which research should be done using this new approach or line of research.

POSSIBLE RESEARCHES	SCIENTIFIC INTEREST	TECHNOLOGICAL INTEREST
Interaction between anti-slip rustic stoneware (GR) with mortars	Effect of reactive alumina on the substrate and the glaze	Control of defects and processing changes
Interaction of the new tiles with micro and nano-pores with mortars	Interaction cement/pores with extremely small sizes	Installing tiles in building construction
Interaction of glass and glassy products (mosaics, structural, porcelain tile) with cementitious agents and adhesive mortars	Reaction of cementitious materials with glasses	Installation and correction of defects

Table 3. Researches that could be tackled immediately.



a) b)

Figure 1. Examples of integration installation pathologies in porcelain tiles fixed with cementing materials. a) Box in floor at Dresden airport, Germany and b) no relation, absence of integration with cementitious material on pedestrian walkway on the Mediterranean coast (original photographs by J. Ma Rincón, 2009).

4. CONCLUSION

Therefore, research into ceramic, glassy, and cementing materials, considering their interrelationships and the synergies of their benefits, both from the structural and finish points of view (interior, exteriors, roof coverings...) with the innovations foreseen for the coming years, will be priority objective of the next IIETcc, Strategic Plan, CSIC for the 2101-13 period. However, to enable this to happen, we must be sure that we will continue to enjoy the support we have received until now from the industrial sectors (including both manufacturers and builders) by investing in future lines (optimised design and mechanical properties with minimal mass) and tackling new microstructural and analytical characterisation techniques, which will enable us to maintain or increase the level of science achieved. In the specific ceramic, glassy and cementitious materials areas, it is considered that this line has a very different approach to those which may seem similar that have been presented by the IETcc for the next Strategic Plan, and also clearly differentiated and specifically aimed at the sector of Castellón, unlike Strategic Plans presented by other ceramic materials research centres. *This future strategy will only be possible if it is given firm support by the ceramic sector, and the Ministry of Science and Innovation, and not just by the personal efforts of the investigators making this proposal*, who in previous years have demonstrated their capacity to obtain funds from the sector industries, because there is a will to work so that the strategy outlined can become a reality to the benefit of Spanish and European R&D+i and to society as a whole. Summarising:

The MISSION: To conduct scientific and technical research in a multi-disciplinary area including both construction methodologies and experts: Building and Public or Civil Works with experience in materials and engineering to strengthen the knowledge, development and application of ceramic materials, and especially ceramic tiles in construction systems.

The VISION of the IETcc. CSIC is therefore to use the INTEGRATION line to become a benchmark centre in the "integrating vision" of ceramic tiles both in Building and in Public Works with the support of sector industries as possible transfers of knowledge.

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