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IV SIMPOSIO INTERNACIONAL Y III CONGRESO NACIONAL DE FERROCEMENTO

4th INTERNATIONAL SYMPOSIUM AND 3rd NATIONAL CONGRESS ON FERROCEMENT

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PROCEEDINGS

Octubre / October
22-25, 1991

La Habana / Havana
Cuba

30 YEARS OF REINFORCED MORTAR EXPERIENCES IN BRAZIL

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ABSTRACT

This paper describes the current concept of ferrocement (called "reinforced mortar" in Brazil), based on 30 years of experiences and research in the Civil Construction field. These experiences are mainly those developed in the precast element applications.

The recent tendencies on research activities at the S. Carlos Group are to study mechanical properties of ferrocement with low reinforcement ratios and to develop its applications in precast elements, in order to obtain thin and lightweight constructions.

By this way, large opening meshes, small sized crushed stone and sand mixes (as to obtain a fine grained concrete), larger reinforcement covers, thickness variation from usual ferrocement to the reinforced concrete ones, prestress application and several production techniques derived from both ferrocement and concrete technology may be used.

Ferrocement is revised in this paper just to attain a higher level knowledge to such an extent that it should be possible to characterize a "second generation ferrocement".

INTRODUCTION

Ferrocement in Brazil is called "reinforced mortar" and it is understood as a particular type of reinforced concrete to be applied in thin-walled elements. Special design procedures and production techniques are indispensable, regarding to several specifications of use, durability and quality requirements

The assumed extended concept of ferrocement does not establish any quantitative differences between ferrocement and reinforced concrete, but only the qualitative ones.

Large opening welded wire meshes are used, steel and cement consumption is to be more and more reduced, and design calculations are quite similar to the reinforced concrete ones. These are some of many aspects that are presented and discussed in this paper.

One can say that reinforced mortar is not truly the same thing of ferrocement, once the performance characteristics may be not the same.

However, many experiences accomplished in Brazil and other countries suggest that an extended definition of ferrocement can provide better conditions to its full development in the Civil Engineering field.

The first applications of ferrocement in Brazil are dated from 1960, when precast roofing beams were produced for many of the S. Carlos Engineering School buildings.

Based on Nervi's experiences, the so called "reinforced mortar" was developed by Schiel & Martinelli (1) by reduçing the cement and steel consumption (at that time) to 700 kg/m^3 and 250 kg/m^3, respectively. Also at that time, woven meshes of 12.7 mm spaced and 1.25mm diameter wires were commonly employed.

But since 1966, with the use of large opening welded wire meshes (50 mm square openings and 2.7 mm wire diameter) in the construction of pyramidal roofs (2), it has been started the development of an alternative reinforcement design to ferrocement.

The design of the folded-plate structures (8 m square plan and central column) was made by means of an experimental analysis on reduced models. At some parts of the structure (25 mm thick plates and only one welded mesh) the steel consumption was about 76 kg/m^3, which still was a very close value to the reinforced concrete ones.

Although at that time there was not a clear knowledge of the concepts related with those practical results, the idea of large opening welded wire meshes using remained. But, paradoxically, it also remained the idea of ferrocement as composite material, that should be defined by means of quantitative parameters, such as steel and cement consumptions, reinforcement specific surface and other mechanical parameters.

Nowadays the definition of ferrocement by means of those quantitative parameters is abandoned and no material composition difference is established between ferrocement and reinforced concrete.

The differences between ferrocement and reinforced concrete are taken as general technological differences, in the same way that differences between reinforced and prestressed concrete are. In this last case, there are no significant differences in the composition of those materials, but the existence of prestressing forces requires special design and construction methods.

From the general definition of reinforced mortar (or extended ferrocement) as a particular type of reinforced concrete, it results the following requirements:

- high quality mortar or fine grained concrete, in order to attend to the small thickness of the elements, to the structural strength and to the durability needs;

- use of a distributed reinforcement of continuous wires (in some cases short fibres), that must be disposed at least in two directions, once the thin-walled sections must be closely reinforced in its all parts;

- special care with the construction procedures, mainly those related to the thin reinforcement cover and special protections means, looking for the required durability level;

- particular methods for the structural design, mainly those related to the cracking behaviour of ferrocement.

Thus, the strength behaviour of ferrocement does not correspond to a synergetic material model, but to a model of associate material, composed by mortar and steel, in which the mechanical characteristics remain the same.

The recent tendencies on research activities at the S. Carlos Group are to study mechanical properties of ferrocement with low reinforcement ratios and to develop its applications in precast elements, in order to obtain thin and lightweight constructions.

STRENGTH BEHAVIOUR OF FERROCEMENT

It can be seen from the Fracture Mechanic Theory (3) that the fracture of plain concrete (or mortar) is reached by the growth of existent microcracks. These microcracks are physical discontinuities in the body, as a result of the formation of many kinds of splits, such as macroscopic and microscopic bubbles, pores and bond faulties between the aggregates and the cement paste.

If we consider an element which is subjected to external tension loads, it can be seen that isostatic tension lines turn aside in the neighborhood of these discontinuities and a stress concentration is installed.

By increasing the tension forces the tension stresses also increase until the material strength is reached. After this, there is a growth of the existent splits (or genetic cracks), that will interconnect themselves as to form the fracture surface of concrete or mortar.

In the case of traditional reinforced concrete, after the concrete fracture the steel bars take all the tensions forces and also restrain the macroscopic crack width.

But in the case of a strongly reinforced ferrocement, a lot of closely spaced wires may obstruct the growth of microscopic cracks, as well as in reinforced concrete the steel bars obstruct the growth of the macroscopic crack width. This interpretation explains the fact that in ferrocement the first crack becomes visible only for relatively large strain.

Many authors had observed that this well known phenomenon, for example:

- Naaman (4) observed that the first crack strength is proportional to the specific surface of the reinforcement;
- Romualdi & Batson (5) observed that the first crack strength is increased from a minimum reinforcement ratio and a wire spacing no higher than 15 mm.

Therefore only with higher steel content and closely spaced and small diameter wires one can reach a meaningful increase of the first crack strength.

It is obvious that by using large opening wire meshes, as the mentioned 50 mm square ones employed in Brazil, the increase of the first crack strength is not significant.

However, even in this case some interesting mechanical properties remain, like the closely spaced cracks and the small crack widths, and so they contribute to make it possible to applicate this "lower performance" ferrocement in Civil Engineering.

As a matter of fact, the performance requirements of a ship hull and those of a housing panel are not the same. Consequently, ferrocement may be properly proportioned in order to attend to the various conditions of the structural elements.

PERFORMANCE REQUIREMENTS OF FERROCEMENT STRUCTURES

In the same way that it occurs with many types of structures, the ferrocement structures must be designed as to satisfy several performance requirements, such as strength, stability, durability and so forth.

Taking ferrocement as a material to be applied to thin-walled structures, it is necessary to adjust the material properties to the construction type and acting forces in the structure, as to obtain the sufficient strength and stiffness. Therefore, the design of shape-resistant structures is recommended.

One of the most wonderful structures designed and constructed by Nervi was the Turim's Exposition Hall, in 1948. The arched roof crosses over a 95 m span by means of ferrocement precast members, which have a maximum thickness of 38 mm. The precast ferrocement elements were assembled with cast-in-place reinforced concrete at the joints.

However, since an arched structural form was adopted, the tensile stresses in the sections are very low. Then, if there are no high tensile stresses in the material, what is the reason to employ a high-tensile performance ferrocement?

In such a case, a low performance ferrocement may be possibly utilized, in order to get a large saving of the wire mesh (and the correspondent labor) cost.

The wire mesh cost saving is often practiced in many trivial ferrocement applications. For example, let us consider the design of small cylindrical water tanks.

The water pressure in the interior of the tank causes tensile stresses on the wall, which may be resisted by ferrocement without large crack widths on service conditions.

In small water tanks (5 - 25 m^3), the tensile stresses are often lower than a good mortar tensile strength (about 2.5 MPa). And so the demanded reinforcement is the only one needed to satisfy the ultimate strength conditions and to resist to other tensile forces due to shrinkage, temperature variations, impact, and so on.

Since in those cases it is not necessary a high level performance of the material, then steel consumptions may be minimized to reach a significant cost saving.

In practice, reinforcement of small water tanks becomes light, and at many reported cases two or three layers of chicken meshes an even bamboo strips are utilized.

On the other hand, this "under-reinforced ferrocement" dos not respect the Nervi's initial idea of ferrocement as a highly cracking-strengthened material.

For all these reasons it is concluded that ferrocement cannot be defined by fixed quantitative parameters such as minimum reinforcement ratio, reinforcement specific surface and others, which are commonly used to differentiate ferrocement from traditional reinforced concrete.

FERROCEMENT DEFINITIONS AND TECHNOLOGY IMPROVEMENT

Many authors are careful in properly making a clear differentiation between ferrocement and reinforced concrete.

Not so long ago in S. Carlos, ferrocement was differentiated from reinforced concrete by the specification of a minimum steel consumption about 200 - 250 kg/m^3.

Nevertheless, in practice this specification was not rigorously followed, as long as many applications were accomplished with lower steel ratios and large opening welded wire meshes.

The nowadays transgression of the original cracking-resistant material is not an accident, but it means the development of an extended concept which is derived from a global analysis of ferrocement technology (6).

From this concept, the cracking strength and other peculiar propertied are given as direct functions of the required structural performance characteristics.

Those special material properties may vary from the lower performance (closely to the ordinary reinforced concrete ones) to the higher performance properties (like high-tensile strengthened ferrocement which is used in boat construction).

This general definition makes it possible to develop a large number of ferrocement applications in Civil Engineering by means of rational design methods and with an important perspective: the cost saving.

In the Civil Engineering field there are many types of construction materials, which have been developed and improved on. In the developed countries those materials supply the needs of material and cost savings, intended for the industrialized construction.

However, looking at the background of ferrocement technology, there were no significant improvements in the material composition and construction procedures since Nervi's experiences.

In despite of the splendid work performed by many research groups and construction enterprises, no substantial progress was reached so as to characterize a "second generation ferrocement".

One can remember some words written by Mario Nervi at the 1st International Symposium on Ferrocement (7):

"... I am convinced that ferrocement could have fruitful applications only in the developing countries were the cost of the labor is proportional to a low level of the cost life..."

"... In the so said developed countries with a market economic system where the unskilled lab our costs about $ 8 per hour the maximum convenience is reached with materials and construction system requiring minimum labor incidence. As said before these are not the conditions for large applications of ferrocement ..."

"... I think that in developing countries it can be find the economical and social conditions for an always larger use of ferrocement in the field of 'first generation', i.e. vessels of small and medium tonnage, stores, slabs and one storied houses..."

"... Vice versa, in the developed countries it is necessary to think to applications of the 'second generation', for which I believe that the most promising one could be the construction of multistoried buildings in seismic areas ..."

These words presented 10 years ago, like those presented by Arnold Damgaard Jensen (8), in the same Symposium, have a special significance, mainly due to the simple key-words "first and second generation ferrocement". These key-words remind us that something must be find to promote the full development of ferrocement in the whole world.

In the papers presented to the Third International Symposium on Ferrocement, H. Ruhle (9,10) demonstrated similar cares with the definition of ferrocement and its improvement in Civil Construction. In a quite similar concept to the Brazilian one, he works with the "fine grain concrete", which is classified as material between ferrocement and traditional reinforced concrete.

In Brazil we think that the "second generation ferrocement" must be related to an extended definition of ferrocement and to the improvement of the material properties, construction procedures, design methods, and technical standardization (6).

We also think that "second generation ferrocement" can be improved and applied in all countries, not only in the developed ones. The construction type may be anyone and high quality may be reached in most of the cases.

High quality is specially important in ferrocement technology in order to assure the high construction durability, which is nowadays a barrier to be overcome.

RECENT DEVELOPMENT OF FERROCEMENT IN BRAZIL

In the last 10 years, ferrocement technology had a significant increase in Brazil, both on the mass-production applications and research works.

The S. Carlos Group members did present some informations about the activities in these areas at the 2nd and 3rd International Symposium on Ferrocement.

One can remember the work performed by Architect Joao Filgueiras Lima (11), the most important in Brazil at the design and mass-production activities. Nowadays, other plants at S Paulo and Campinas cities are in full operation, and the Federal Government are planning to install more 20 plants in all the country, as to produce 5,000 school buildings.

The Brazilian Ferrocement Code (12,13) was approved in 1989 and it is in effect all over the country. One of the strongest limitations is that ferrocement cannot be applied in corrosive environments without special protection means. This precaution is very important because ferrocement is not truly corrosion-resistant itself. Even when a good quality Portland cement mortar is used, a reinforcement cover about 6mm may be insufficient and a corrosion process can be installed. Furthermore, ferrocement constructions have demonstrated a high sensibility to design and production mistakes, and then many kinds of pathological problems had been observed.

Mainly in the lightweight prefabrication, quality assurance is a special matter that must be observed as to provide the proper reliability that a product will meet the defined requirements. Thus a lot of specifications and charges must be taken, and more researches are needed.

One of the S.Carlos Group research guidelines concerns with the cement mortar quality increasing. Some results demonstrate that a simple aggregate grading optimization can provide the reduction of cement consumption and a better quality mortar, both in strength and durability sense. The use of concrete admixtures, some polymer products, microsilica and ordinary fly ashes is being researched.

The application of alternative reinforcements, as expanded metal meshes, short steel fibers and polymer fibers and meshes, also characterizes a research line, intended to extend their use in Brazil or to develop new reinforcing materials.

Mechanical properties of ferrocement are ever in study, specially those related to the cracking performance. The prestress technique application to ferrocement (or generally to a thin-walled reinforced mortar or "fine grain concrete") has a great potential in the lightweight prefabrication and some of the precast concrete production techniques can be adapted to ferrocement.

Curing procedures like water immersion and steam are currently in use at the Brazilian plants, and their relationships with the many intervening factors (temperature, curing time cycle, cement type, admixtures, etc.) and the final product quality have been considered in the studies.

Finally, the development of precast structural elements and construction systems is a subject of many works performed by the S.Carlos Group, in many cases in conjunction with Civil Engineering contractors and government institutions.

CONCLUSIONS

Ferrocement technology must be deeply revised in order to attain a higher level knowledge to such an extent that it should be possible to real characterize a "second generation ferrocement".

An extended definition of ferrocement may contribute to widen its application in Civil Engineering. The elimination of too much strong and restrictive quantitative specifications of ferrocement, both in its composition and performance, is suitable to the full development of this technology.

However, the knowledge improvement of ferrocement mechanical properties, although very important, is not the main factor that brakes ferrocement to become widespread.

Idealizing ferrocement as a special type of reinforced concrete to be applied in thin-walled elements, we think that today two factors are to be seen the most critical: durability and cost.

Material and product quality level and its correlation with durability are important factors to ferrocement development. Ferrocement durability is nearly always an unknown variable that restrains the mass-production and many single applications.

A systematic inspection over existent ferrocement constructions in Brazil had shown that most of the time the material poor quality and bad execution conditions are the main causes of construction deterioration.

Prefabrication and high quality production control are generally recommended for durable constructions. Uncontrolled execution, like the one that occurs in "make-yourself" type constructions, is recommended only for small responsibility and few years' life-time constructions.

Although some ferrocement applications may be cheaper than the other material alternatives, ferrocement is not a low-cost material in comparison with traditional reinforced concrete.

Steel meshes are often expensive and mortar usually demands high cement consumption.

The high cost of steel meshes is due to technical production reasons and to its low demand in Civil Engineering. By increasing ferrocement applications it is possible to create an interesting market to increase the financial investments in the industrial area. Consequently, the steel mesh cost should be reduced.

High cement consumption in ferrocement mortars is generally due to low water/cement ratio necessity (to minimize mortar permeability) and workability conditions, not due to strength conditions.

The high cement consumption raises ferrocement cost and it brings up higher shrinkage and other problems. At under-reinforced ferrocement applications it is possible to reduce cement consumption by using higher grade aggregates (for example, by the use of fine crushed stone to correct the grading curve of the natural sand). In general, one can use superplasticizers, microsilica, latex and other admixtures as to reduce the total water content and the cement consumption; to increase the plasticity of fresh mortar; to reduce the pore volume and the permeability; to obtain other special properties.

Ferrocement cannot be seen as an apart material from the other ones. It should be improved and become competitive in the construction market.

Ferrocement technology improvement may contribute to the self-same reinforced and prestressed technology, as long as it can teach engineers, architects and contractors how to build lightweight, beautiful and durable structures.

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