INFLUENCE OF INTERFACIAL TRANSITION ZONE ON THE MECHANICAL BEHAVIOR OF CONCRETES WITH ADMIXTURES

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ABSTRACT. Researches of literature sources on interfacial transition zone (ITZ) between aggregates and cement bulk paste are studied. This paper revealed the impact of water binder ratio on ITZ properties, its microstructure and thickness. Results of using supplementary cementitious materials (mineral admixtures) like cement replacement materials in concrete performance are shown. Chemical admixtures and their place in forming ITZ’s microstructure and properties are discussed as well. Influence of ITZ on the mechanical behavior of concrete at different load cases is analyzed.

KEY WORDS: interfacial transition zone, aggregate, mineral additives, chemical admixtures, mechanical behavior

1. Introduction

Information about connection between mechanical behavior of cement-based composites and properties of interfacial transition zone (ITZ) between aggregates and cement bulk past and their interaction is presented and proven in the explored literature source [1-14], [16-22]. Significant role, in ITZ’s structure formation and its properties incl. and its thickness plays water/binder ratio (W/B), quantity and type of cement, quantity, type, size, shape, texture and mechanical properties of aggregates and presence of mineral additives and chemical admixtures in a concrete mix. Specific structure and properties of ITZ influence mechanical behavior of composite materials subjected to different load cases and various environmental impact [1-5], [7-22]. Resistant and deformation properties of materials largely predetermine initiation and propagation of cracks, so the crack development is observed as one of the factors influencing mechanical behavior of a composite. Basically, in this paper are presented cases where deformations and micro - cracks exist or are obtained in the transition zone, and existent of initial deformations and micro - cracks in mortar matrix and/or aggregates is neglected. The influence of both mortar matrix and aggregates over micro - crack initiation within the ITZ is observed, as well as the subsequent composite’s mechanical behavior.

2. Influence of aggregates

A major and approved role in forming a good, strong connection „interfacial zone – aggregates” plays shape, type of aggregates and texture of the grains, which
can result in improved mechanical behavior of concrete [1,2], [8]. As the thickness of ITZ is decreased the effect of the aggregate’s type on transition zone’s properties is enhanced. A narrower ITZ can be obtained in concretes with low W/C and reduced porosity [1]. Cracks initiation, their development and propagation exactly within a transition zone is observed when outer loading is applied and ITZ is the weakest link in a composite. In a case of intentional effect of a compromised transition zone [1, 2], [6], higher strength characteristics are possessed by the aggregates used in the mix than a matrix’s one. Akcaoglu et al. (2005) concluded that, the bigger the difference between ITZ’s strength and that of bulk cement paste the higher is the possibility of micro-crack initiation within ITZ with aggregate grains.

The “wall effect” is the main reason of such zone, with different microstructure in the immediate vicinity of grains’ surface, to exist. During mixing, dry cement particles are unable to become closely packed against the relatively large particles of the aggregate. There is less cement present to hydrate and fill the original voids [2], [7], [9], [13]. The second fact to note is the bleeding effect beneath the coarse aggregate grain during the vibration time. In consequence the transition zone has a much higher porosity than the hydrated cement paste further away from the coarse aggregate. [2], [7], [9].

Cooper slag aggregate concrete (CSAC) and gravel aggregate concrete (GAC) have been prepared and compared each other about flexural, compressive strength and impact behavior [2]. The obtained results show that CSAC have higher flexural tensile and compressive strength. This is partly due to the strength characteristics of the aggregate and partly due to the high Ca/Si ratio through the ITZ and more homogeneous internal structure of the CSAC. Much denser, stronger and rougher, and higher crystalline copper slag aggregate produced a dense, stronger and much rougher ITZ, which in turn provides more resistance to impact. Erdem et al. (2012) concluded that ITZ with higher surface roughness may result in a higher load-carrying capacity of concrete by contributing to more energy dissipation within the mixture, and thus more resistant to impact.

A critical combination of factors that compromises the transition zone is shown in [1] - high strength concrete with W/C = 0.42 and model of single spherical steel aggregate ( various size spherical steel “grains” – 9,12,19,25,32 mm) inserted into the center of the specimen. The obtained mortar matrix is more homogenous but and more brittle in failure. In combination with (in a case of low W/C) micro-crack accumulation and stress concentrated in the narrower transition zone and pre-induced tensile stress by the inserted rigid and smooth steel sphere, results in decrease mechanical properties of the specimens. The inserted “aggregate” (steel smooth ridged sphere) has reduced adhesion with the ITZ and mortar matrix. The described combination contributes to a bigger difference in elastic moduli of the mortar matrix and this of the transition zone. As the size of the steel aggregate increases the interfacial bond strength decreases (“wall effect”) and contributes to more porous and defective transition zone [1, 2],[7], [9].
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A great interest in forming a bond “mortar matrix – aggregate” in concrete mixes with lightweight aggregates is given to the density of the outer layer of the coarse aggregates. [8, 9]. When the outer layer is dense, the ITZ is similar to this in normal weight concrete. It is more porous than the bulk cement paste. If the outer layer of the coarse aggregates is porous, densification of the ITZ is obtained due to the better adhesion between grains and cement paste.

The influence of the ITZ between the old paste matrix and old grains and this between the new mortar matrix and recycled aggregate, is important when it comes to recycled aggregate concrete (RAC) [10,11],[13].

In a scientific project [11] is stated that ITZ influenced the mechanical behavior of RACs. Authors analyzed the effect of mixing approaches on the strength characteristics of hardened RAC. The focus is on the possibility of nanomachanical properties’ enhancement of the ITZ and its microstructural improvement when two steps mix approach (TSMZ) is adopted. The results show that TSMA can effectively reduce water layers and the size of CH crystals, which are formed around the recycled concrete aggregate’s surface. Compared with normal mix approach (NMA), the TSMA contribute to enhanced hydration and C– S – H gel formation, as well as less volume fraction of the pores and reduced presence of CH crystals in the new ITZ. This can explain the improvement in RAC compressive strength when TSMA is utilized. For the new ITZ with TSMA, the cement slurry permeates into the porous old paste matrix and fills up the voids and cracks, which improve the microstructure of the new ITZ. However, for the new ITZ with NMA, there is a significantly loose microstructure that contains a large volume of porosity and CH crystals. [11][13]

3. Influence of mineral additives

Utilization of mineral additives like cement replacement quantity in contemporary concrete manufacturing has increased during the years. Their placement in concrete mixes contributes to enhancement properties of the composite. Mineral additives have a good effect on the concrete structures, as they density mortar and transition zone and reduced ITZ’s thickness. [3], [5], [8], [14- 20] A combination of low W/C ratio, plasticizer, silica fume (SF) or fly ash (FA) in a concrete mix could significantly reduce or lead to disappearance of ITZ in hardened concrete [8], [14]. Thereby, the produced concretes are highly durable and less vulnerable to micro – crack initiation.

Quantity and type of used mineral additives are important in improving the mechanical characteristics of the composite in different ages. If the early age concrete is an object of performance the best results are to the mixes with SF in them. When 7,5 % cement replacement quantity of SF is used the early compressive strengths are higher than 15% SF replacement concrete. The size of mineral additives’ particles and their specific surface also play serious role in microstructure and mechanical performance of a composite. For example silica fume particles are 0.1-0.3 μm, and these of ground granulated blast-furnace slag (GGBS) are10-20 μm, which is one of the reasons of higher strength characteristics of SF concretes. A
reduced compressive strength of the concrete containing pulverized fuel ash (PFA) is due to its less pozzolanic reactivity than SF’s. Elahi et al. [16] explains the advantages in increasing compressive strength of SF concrete mixes with higher pozzolanic reactivity of that mineral additive, its ability to fill up pores and voids in the composite and the transition zone as well. This is due to the particle size of the SF and the reduction of unbounded Ca (OH)$_2$ and transition zone densification. The compressive strength of ternary mixes of PFA and GGBS (Portland cement + two mineral additives, one of them SF) were observed to be greater than their binary mixes (without SF), which is considered to be due to the contribution made by SF. The use of SF reduces the porosity of interfacial transition zone (ITZ) in concrete due to their ability to fill the pores in ITZ with fine silica particles and reduction of the amount of calcium hydroxide (CH) in the ITZ due to its high pozzolanic reactivity [16].

In a researcher over the influence of metakaolin (MK) on the properties of mortar and concrete Siddique et al. (2009) concluded that the micro-hardness of the bulk matrix and, to a greater degree, the ITZ increased when metakaolin was used as a partial replacement for Portland cement. Inclusion of MK reduced both total and basic creep of concrete, with a greater reduction in creep at higher replacement levels. The reduction in creep could be attributed to a denser pore structure, stronger paste matrix and improved paste aggregate interface of MK concrete mixtures as a result of the formation of additional hydrate phases from secondary pozzolanic reaction of MK and its filler effect [18, 19]. A decreasing ability to shrinkage deformation and cracking development were obtained due to restricted shrinkage of such mixes [19].

In other research [21], focused on effect of SiO$_2$ micro- and nanoparticles on the mechanical behavior of high performance self-compacting composite, authors revealed mineral additive’s contribution to improved compressive and splitting tensile strength. The higher strength achieved in concrete mixtures containing SiO$_2$ micro and nanoparticles is due to the rapid consumption of crystalline Ca(OH)$_2$ which quickly are formed during hydration of Portland cement specially at early ages as a result of high reactivity of SiO$_2$ nanoparticles. As a consequence, the hydration of cement is accelerated and larger volumes of reaction products are formed. Concrete structure and its “aggregate – mortar” bond is improved.

4. Influence of chemical admixtures

Use of chemical admixtures in concrete mix is a powerful contrivance when special concrete properties are required [22, 23, 24]. Their inclusion changes concrete structure, positively results in “cement mortar – aggregate” bond and improved mechanical properties. Shrinkage-reducing agent (SRA) and an expansive additive (EXA) were combined and added to HPC mixtures to minimize or fully reduced autogenous shrinkage strains and induced, by shrinkage strains internal stress [24]. The results shows significant, even fully reduction of shrinkage strains and stress. As the early-age autogenous shrinkage is more significant, with 80% of
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its magnitude, so the addition of a combination of SRA and EXA contributes to decreasing ability to crack development in early age concretes [24, 25].

Chemical admixtures usually are components in HPC mixes. Water reducers, plasticizers, supper plasticizers reduced water requirement with fixed consistency and contribute to improved transition zone and the structure of composite material at all [15]. In [26] is described that polynaphthalene sulfonate superplasticizer influence’s on the ITZ between aggregates and cement bulk paste depends on: dosage polynaphthalene sulfonate, W/C ratio, fine aggregate/coarse aggregate ratio, type of coarse aggregate. The improved picture, within the transition zone when low W/C ratio combined with polynaphthalene sulfonate super plasticizer in concrete mix is a fact. But if the W/C ratio is higher, a risk of bleeding effect and segregation appeared as well and the quantity of the water around the aggregate grains is enhanced. Thus the transition zone is more vulnerable to strain deformations and crack initiation and reflects on the other composite phases.

The analysis of the reviewed literature gives grounds to assume that the characteristics of the contact area significantly affect the structural and the mechanical properties of composite materials. The proper selection and combination of the components of the concrete mixture lead to obtaining a sealed structure of the transition zone, an improved bond between the matrix and the aggregates or even a complete absence of the transition zone. The resulting materials have improved mechanical properties, improved corrosion resistance, reliability and durability.

REFERENCES

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[23] European Standards EN 934-2 - Admixtures for concrete, mortar and grout - Part 2: Concrete admixtures - Definitions, requirements, conformity, marking and labelling;


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