STEEL-SLAG AS SUBSTITUTE TO NATURAL AGGREGATES, PROPERTIES AND THE INTERFACIAL TRANSITION ZONE

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Abstract

Steel-slag is a residual product of the steel industry that has potential ability to pollute the ground water and soil containing heavy metals. To overcome this problem, attempts have been made for using the slag as substitute for both coarse and fine aggregates in concrete. The solidification process will prevent the metal components from polluting the water and soil.

Test results on the mechanical properties of slag-concrete showed that while the compression strength of slag-concrete increased significantly as a function of slag-to-natural aggregate's use, the tensile strength dropped accordingly.

The substitution of fine-slag to Muntilan sand was even more negative, the compression strength decreased as a function of slag use. Research into the influences of the Interfacial Transition Zone was conducted, since the ITZ itself forms a weak link within the concrete matrix.

The SEM tests were performed at the Quarter Laboratory, Department of Geology in Bandung using a Scanning Electron Microscope type JEOL.

Keywords: *slag, fine and coarse aggregates, compression and tensile strength.*

Introduction

Research conducted at the *Construction and Material Laboratory, Civil Engineering Departement, Diponegoro University (Han and Tudjono, 2008, 2007)* concluded the following:

1. Workability of fresh concrete mixes increase as a function of slag usage resulting in a more compact concrete with a higher mass density.
2. 28 days compression strength increases as a function of *slag - to-conventiona l -aggregate* percentage (figure 1).
3. The ratio of *tensile - to-norma l -concrete* strength decreases as a function of increase in coarse slag usage (figure 2).
4. Fine slag influences both workability and compression strength negatively.

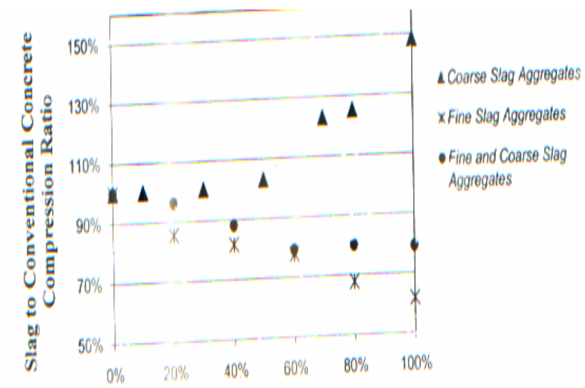

Figure 1. Compression Strength of Slag Concrete (Han, Tudjono 2008, 2007)

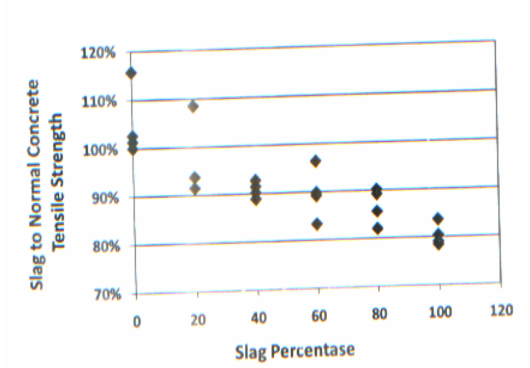

Figure 2. Tensile Strength of Slag Concrete (Han, Tudjono, 2008, 2007)

This research work was accomplished by substituting the Pudak Payung aggregates gradually by the steel-slag, and by replacing the Muntilan sand by fine slag. All specimens were tested at age 28 days.

The deviation of *compression-to-tensile-strength-relation* arouses the question as whether the cause is originated from the nature of aggregates itself and its *Interfacial Transition Zone* in concrete.

Cement Hydration and the Interfacial Transition Zone

Concrete is a heterogenic material consisting of aggregates embedded in a cement matrix. The me-chanical properties of this material are influenced by their interaction. Figure 3 shows the physical appearance and the stress-strain relationship of concrete making components.

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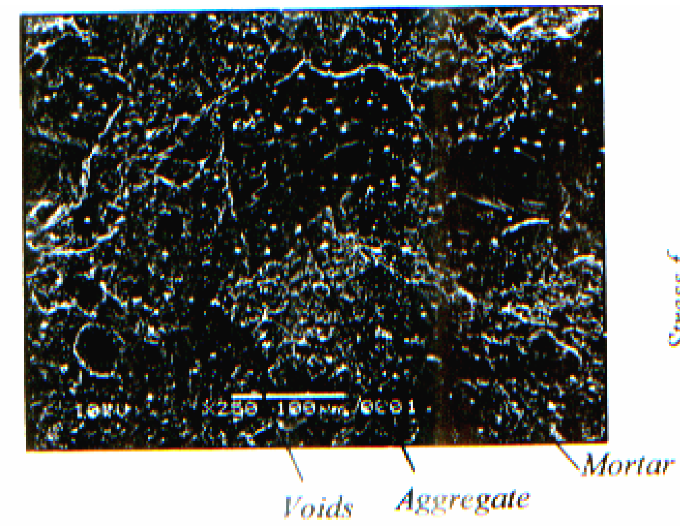

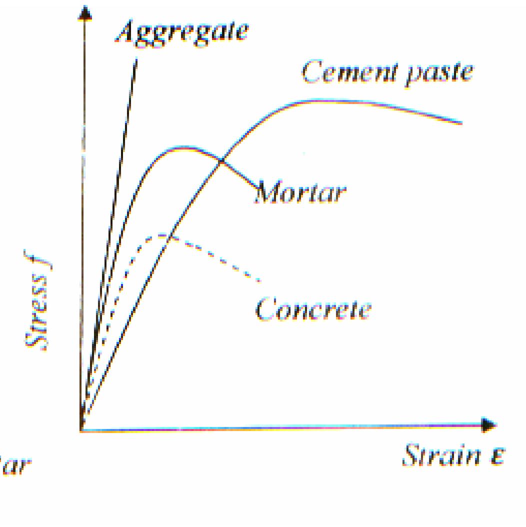

Figure 3a. Concrete Cross Sectio

Figure 3b. Stress-Strain relationship of concrete components

The formation of concrete is a product of cement hydration. Cement is a chemical component consisting of $(C_aO)_3(S_iO_2)$ commonly noted as C_3S, $(C_aO)_2(S_iO_2)$ noted as C_2S and $(C_aO)_3(Al_2O_3)$ noted C_3A (fig. 4).

The hydration process results in C-S-H, CH and ettringite crystals are as following:

- 2C3S+11H?3CH+C3S2H8
- 2C2S+9H?CH + C3S2H8 or (C-S-H)
  Calcium Silicate Hydrate
- C3A+3CSH2+26H?C6AS3H32 (Ettringite)

C-S-H is a poorly crystallized spine formed amorphous crystal with a very small dimension so that even with an electron-microscope it not observable clearly.

CH is a tubular, hexagonal excellent crystallized mineral. The crystals are large so that they often can be observed with the naked eye.
Ettringite are good crystallized prismatic needle formed crystals.

The *C-S-H*, *CH* and *ettringite* crystals influence the concrete properties at the Interface Transition Zone (ITZ).

Figure 4. Hydrated Cement Crystals (Han Aylie, 2009)

Interface Transition Zone (ITZ)
From microscopic view the position of ITZ is clearly illustrated in figure 5.

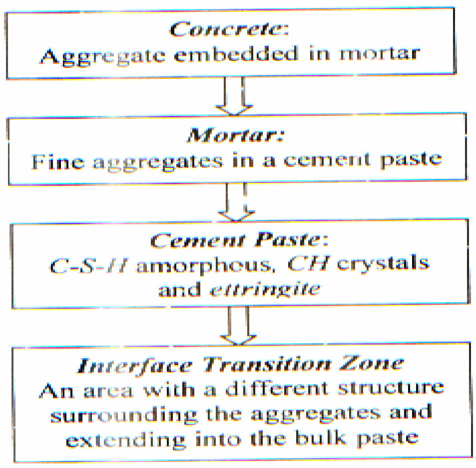

Figure 5. Illustration of ITZ' position within the concrete mass

Diamond and Barnes (1978, 1979) concluded that the ITZ consist of a *duplex film* of CH and C-S-H crystals having a thickness of 0.5 – 1 ?m. On top of this layer is the transition zone 50 ?m thick formed by hollow-shell CH crystals and ettringite.

Zimbelmann (1978) defined the ITZ in three layers. The *contact layer* close to the aggregate surface 2-3 ?m in thickness consist of CH and ettringite crystals. On top of this layer is the *in-termediate layer* 5-10 ?m, consisting of ettringite and C-S-H needle-formed crystals and sparingly distributed flaky CH crystals. Close to the bulk paste is the dense *transition zone* 10 ?m in thickness.

Yang and Guo (1988) found out that the ITZ is a *duplex film* formed from CH crystals and a thin C-S-H layer. The next film is a network of ettringite and C-S-H crystals having a very high porosity level (figure 6).

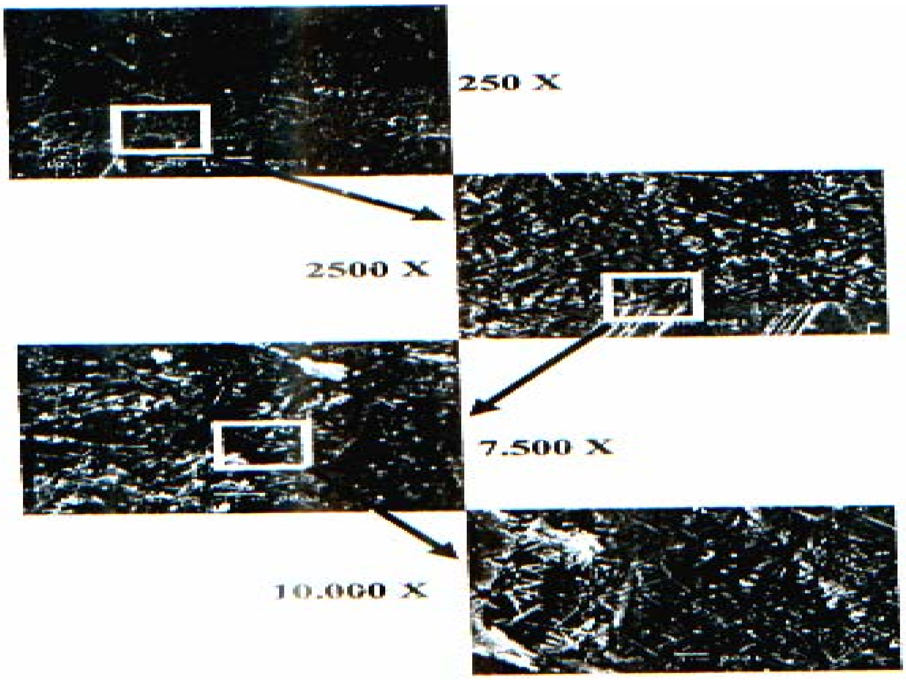

Figure 6. SEM images of hardened concrete (Han Aylie 2009)

Interface strength and its influence on concrete
The interface Transition Zone is recognized as the *"weak link"* in concrete *(Larbi, 1991, Mindess, 1996, Diamond and Huang, 1998)*. The weakness is due to low adhesive strength, highly depending on the volume size voids in the ITZ *(Mehta, 1986)* while the characteristics of large crystals tend to posses less adhesion capacity. These Calcium Hydroxide crystals have an orientation that allows cracks to occur along their weak bond plane. Further, micro cracks tend to propagate along the weak plane of the crystals following the *Van der Waals* forces' plane.

The ITZ is found to be an intermediate layer between the aggregate to the hardened cement mortar *(Maso, 1996).*

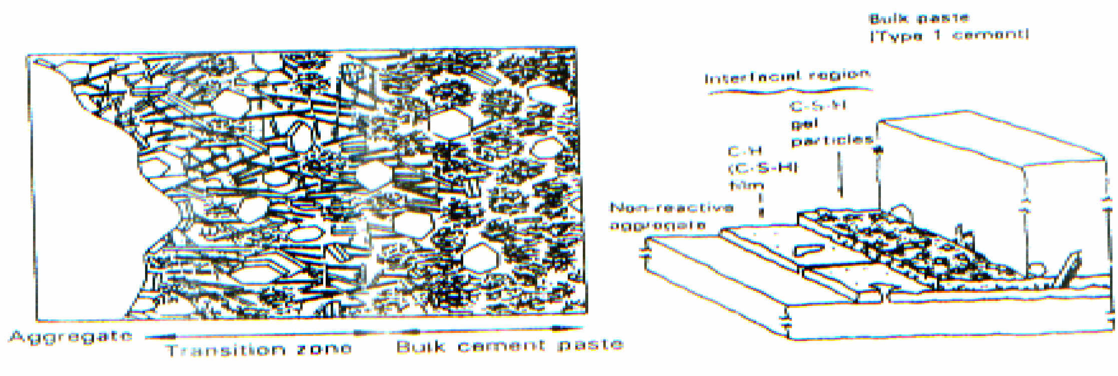

Figure 7. Visualization of the ITZ (Larbi, 1991; Mindess, 2003)

This intermediate layer has a micro-structural different composition. The crystal formations within the layer are highly non-homogeneous. The distinctiveness of this ITZ layer depends on various aspects, but among them the aggregate's characteristic is the most influential. Physical properties of aggregate's affecting the ITZ are *area-to-volume ratio*; dimension and porosity *(Mehta, 1986; Mindess, 2003).* Figure 7 shows a diagram of the ITZ for conventional, natural aggregates.

The present of voids in the cement mortar are oppositely correlated to the water cement factor and will decrease in time. These voids will enable larger crystal to form during the cement hardening process. Other factors influencing the ITZ for-mation are the presence of a water film sur-rounding the aggregates due to bleeding.

Aggregate Characteristics and SEM Readings

The based on test result *(Putra, 2006, Purwono, Shofianto, 2007)* is was shown that physical properties of slag and natural aggregates are similar, except that the slag has a slightly higher density, *Los Angeles* and *Impact* value combined with a lower absorption rate. The slag has generally a better particle shape with a rougher texture. The low absorption will more likely lead to a higher workability. This is explained due to the presence of unconnected voids. According to *Indonesian Code* all values are within the permissible range.

For the SEM analysis, the samples are observed based on the *Secondary Imaging* method. The reading is performed on the aggregate surface and along the ITZ's concrete fracture surface. A layer of the past is grinded and attached to the platinum molt, the observed surface remains virgin. A reading at 250 times is set to localize the observed the aggregates and ITZ, followed by readings of 5.000 to 7.500 times. The aggregate details are presented in figure 8 and 9.

Figure 8a Pudak Payung at 30 X

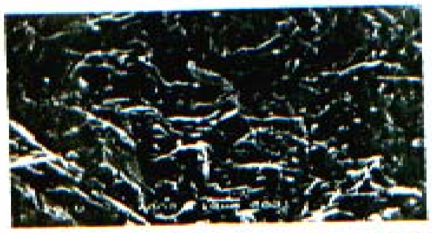

Figure 8b Pudak Payung at 1.000 X

Figure 9a Coarse Slag at 30 X

Figure 9b Coarse Slag at 1.000 X

At 30 times, the slag has a rougher texture with more voids, suggesting a better bonding to the mortar when in compression. At a closer view however, the surface of slag appears smooth and fine, having large plates. The Pudak Payung aggregates on the other hand, demonstrates a better bond media for the cement mortar.

ITZ of slag versus Pudak Payung aggregates

Form visual examination of 28 days test cylinders it was shown that the percentage of *bond failure* within the slag-concrete was noticeable lower than of the Pudak Payung aggregates. This finding supported with the SEM readings (figure 10 and 11); confirm that a better ITZ is present at slag surfaces.

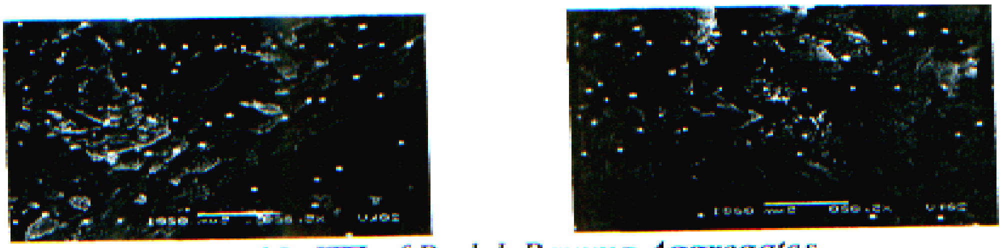

Figure 10. ITZ of Pudak Payung Aggregates

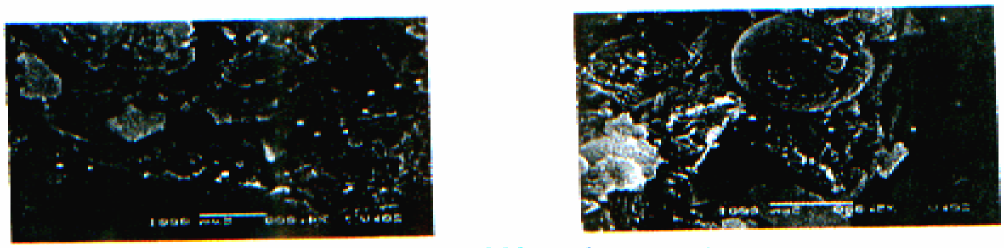

Figure 11. ITZ of Slag Aggregates

Figure 10 shows an approximately 0.1 μm gap between the aggregate and the cement mortar; the gap is noticeable smaller for slag concrete. Also the Pudak Payung ITZ shows a different constitution. A thick layer of C-S-H ranging from 2 to 5 μm confirms the findings of *Diamond and Barnes (1978, 1979); Zimbelmann (1978); Yang and Guo (1988)* and other former researchers.

On top of this layer ettringites and CH crystals are detected, while round formations are suggesting the presence of fly-ash in the cement. This layer expands into the cement mortar. *Diamond and Barnes's* description fits best for overall the Pudak Payung ITZ.

Observing the slag ITZ (figure 11) it can be seen that a different structure is present. A gap smaller than 0.1 μm is observed followed directly by a dense layer, 5 to 10 μm in thickness probable C-S-H crystals. On top of this layer CH crystals are distinguish, reaching into the cement mortar. No ettringites or voids are identified.

Conclusion and Future Research

The Interfacial Transition Zone is known as the weak link in concrete. The behavior of slag-concrete that deviates from normal aggregates concrete suggest that this deviation is originated from its ITZ.

When observed with the naked eye, the slag suggests a better surface for bonding since it has a rough and irregular surface. But on closer scale the particles are smooth and shiny while Pudak Payung has a much better bonding area. Physical properties' test results showed that both Pudak Payung and slag are suitable to be used in concrete since all Indonesia requirements are met. The ITZ of Pudak Payung and Slag demonstrate a significant difference, both constitutional and dimensional. Further research work is required to observe crystal growth by testing samples at various ages. Also the tests should include the addition of silica fume, since this material improves ITZ performances. Tensile behavior for all slag types, coarse and fine should be evaluated.

While the SEM analysis provides only qualitative data, additional tests such as *Sulfate Attack, Chloride Penetration and Carbonation* can provide the researcher will quantitative data that can be correlated to the mechanical properties of concrete.

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