



## **STEEL-SLAG AS AGGREGATE SUBSTITUTE'S INFLUENCE TO CONCRETE'S SHEAR CAPACITY AN EXPERIMENTAL APPROACH**

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### **ABSTRAK**

*Penggunaan slag baja sebagai pengganti agregat kasar pada beton telah menunjukkan nilai-nilai positif seperti meningkatnya kuat tekan beton, perbaikan kelacakan (workability) adukan segar dan pengurangan pencemaran logam berat dengan adanya proses solidifikasi dalam semen. Karena masa jenis beton slag juga meningkat, maka perlu diadakan penelitian lanjut tentang kemungkinan penggunaan beton-slag ini sebagai komponen struktural. Peningkatan kuat tekan beton yang seiring dengan peningkatan massa jenisnya membuka peluang penggunaan bahan ini sebagai elemen struktur yang tertumpu pada tanah, seperti misalnya balok basement, balok tie-beam dan rigid pavement. Namun demikian perilaku beton-slag terhadap respons geser (shear) belum diketahui dengan pasti. Uji laboratorium ini meneliti perilaku geser balok beton-slag yang diberi tulangan tunggal sedemikian sehingga pola kehancuran balok dipengaruhi oleh kehancuran gesernya. Hasil pengujian dibandingkan terhadap balok identik dengan agregat Puduk Payung sebagai elemen kontrol. Pengamatan terhadap balok-balok ini menunjukkan bahwa penggunaan slag meningkatkan kapasitas geser beton sebesar 11%, serta tidak terjadi pergeseran pada pola kehancuran.*

**Kata kunci:** Slag, Agregat Kasar, Kuat Tekan, Kapasitas Geser.

### **ABSTRACT**

*The use of steel slag as a substitute to natural aggregates for concrete increases the compression strength and workability of fresh concrete mixes. Furthermore, by solidification in the cement matrix, the pollution of heavy metals into soil and groundwater can be reduced significantly. The utilization of slag-concrete to be used*

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*as structural components need to be conducted especially since mass density increases as a function of slag percentage. Possible aspects are among others, basement components, tie-beams and rigid pavement elements. All these structures rest directly on supporting under layers, reducing their negative high mass-density effect. While compression and tensile behavior have been explored, the shear capacity of slag-concrete has yet to be investigated. This experimental work covers the behavior of singly reinforced concrete beams failing under shear mode. The result is compared to the controlling element, identical to the concrete-slag beam. The controlling beam uses Puduk Payung aggregates. The experimental research shows that the slag-concrete's shear capacity increases 11% to the Puduk Payung concrete. The mode of failure however, remains the same.*

**Keywords:** *Slag, Coarse Aggregates, Compression and Shear Strength.*

## INTRODUCTION

Former research work has concluded that steel-slag as a waste product of the steel industry is an excellent substitute for coarse aggregates in concrete (Tudjono, Han, 2007, 2008). The benefits lie within the capacity of overcoming environmental issues of water and soil pollution since solidification into the cement matrix can reduce the impact of heavy metals (Kurniawaty, 2006; Purwono, 2007).

The use of slag can also control the rapid degradation of natural stone resources and prevent illegal blasting and land-cutting. As from structural point of view, the slag concrete has a higher compression-to-normal-concrete ratio, while workability of fresh mixes is improving.

Since the mass-density of slag is much higher than natural aggregates, the resulting concrete has also a higher density. When designed as structural elements, this high unit weight will diminish the advantage in compression strength increase. Thus, the slag concrete is best used on elements

directly in contact with supporting ground such as basement components, foundation elements and rigid paving.

Since tensile strength of slag concrete does not follow the increase in compression strength, reinforcing the tension area will be the solution to overcome this weakness. However, the behavior of slag concrete in shear has not been investigated.

To enable the observation of shear behavior, a laboratory-scaled experiment was conducted. These tests will also provide valuable information on the ductility behavior of slag concrete components.

## TEST SET-UP AND ELEMENT'S SPECIFICS

The test set up was designed in accordance to ASTM C78 - 08 "Standard Test Method for Flexural Strength of Concrete". Here a simple beam is loaded with a two-point loading system, and the behavior observed by measuring the load, deflection and strain (Figure 1).

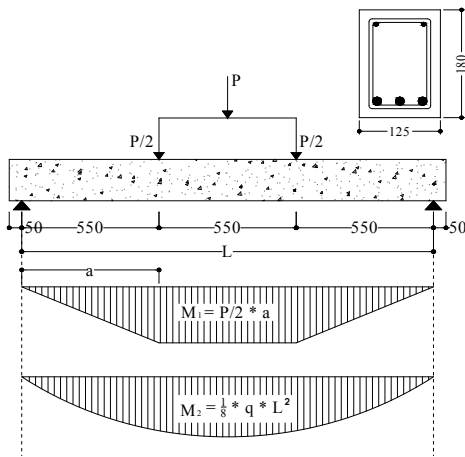


Figure 1. Schematic of tested beam

The beam is designed with a dimension of 125 x 180 and a length of 1.800 mm. The reinforcing steel in tension is a 3D13 mm deformed bars configuration with an area of 398 mm<sup>2</sup>. The steel-to-concrete ratio is  $\rho = 0.0209$ . Based on the assumption of a 35 Mpa compression strength the maximum steel-to-concrete ratio ( $\rho_{max}$ ) is 0.02845. The applied reinforcing steel is approaching  $\rho_{max}$  to ensure shear failure.

The stirrups as well as the compression reinforcements are reduced to the minimum so that the failure mode will not be governed by flexure. The compression bars and stirrups are 6 mm in diameter and assumed only as montage elements.

Two identical beams are prepared, the controlling element using natural Puduk Payung aggregates, and the second specimen using a 100% of slag aggregates substituted by volume method. Additional cylindrical specimens 150 x 300 mm are prepared to

measure the existing compression strength of concrete. The beams and cylinders are tested at a concrete age of 28 days.

To measure the vertical deformation, two LVDT's (Linear Vertical Displacement Transducer) were placed at center-points on both sides of the beam, while strain gauges were attached to measure the elongation of steel in tension. The incremental load was recorded by a load cell 500 kN in capacity, placed on top of the loading device (Figure 2).

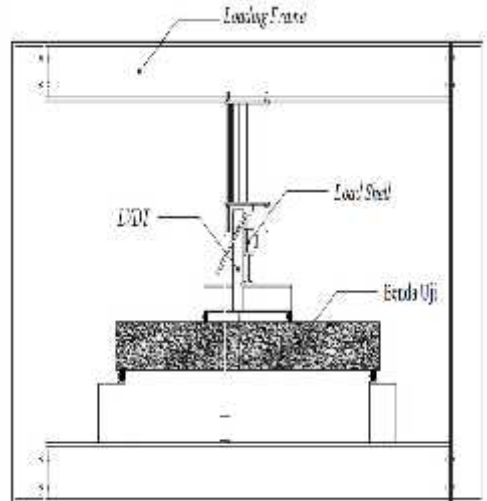


Figure 2. Test set up of specimen

The beam was supported by a roll and hinge on the far ends simulating a simply supported beam. The load was increased at a rate of 10 kN and maintained for 5 minutes. To ease the observation the beam was painted white and divided into a grid system on all sides. The loading was terminated at cracking of the beam. The actual beam prior to loading is shown in Figure 3.



Figure 3. Beam specimen prior to loading

### RESEARCH SIGNIFICANCE

The knowledge to the behavior of *slag-concrete* is crucial for the application of this material as a structural element. As with normal concrete, the tensile strength is much lower than the compression strength, resulting in a weak area at the tension zone.

When section analysis is based on the cracked-section method, the tensile capacity of concrete is neglected, and tension stresses are carried by the reinforcing steel. Transfer is conducted by bond between the steel bars and the surrounding concrete mass. The section can now carry additional loading up to failure, the failure mode can be distinguished as concrete compression failure or steel tensile failure. Since an element is not only subjected to flexure, shear failure is another mode that can result in sudden collapse of an element.

The shear strength of normal concrete is expressed as a function of the compression strength square-root multiplied by a coefficient. For slag-concrete however, the coefficient is not known, and using the normal concrete coefficient could be highly conservative and risky.

Tests for obtaining the shear capacity of concrete directly, involves a cumbersome and expensive procedure. An indirect approach is therefore chosen, that will give a good picture of the overall shear behavior.

### TEST RESULTS

Based on the cylinder compression test results it was shown that the 3-days *slag-concrete* compression strength increased 14.61% to normal concrete, while 28-days strength demonstrated an increase of 9.29 %.

At an identical loading rate the beam were tested and all perimeters

recorded. The normal concrete specimen and slag-concrete beam both failed in shear at a failure loading of respectively 60.1 kN and 70.1 kN. The load increase therefore is 16.64%. The load-deformation response of specimens is shown in figure 4.

The shear strength is customary expressed as function of concrete's compression strength  $f'_c$  as:

$$v_c = \frac{1}{c} \sqrt{f'_c} \dots\dots\dots(1)$$

Where:

- $v_c$  = shear capacity of concrete (Mpa)
- $f'_c$  = compression strength of 28 day's cylinders (Mpa)

$C$  = shear coefficient

Based on the shear forces of the beam the relation can be expressed as:

$$V_c = v_c \cdot b_w \cdot d \dots\dots\dots(2)$$

Where:

- $v_c$  = shear capacity of concrete (Mpa)
- $b_w$  = with of the beam section (mm)
- $d$  = distance from the extreme concrete fibers in compression to the tension steel (mm)

Neglecting the contribution of montage steel and bond between the longitudinal reinforcement and concrete, the shear coefficient is calculated (Table 1):

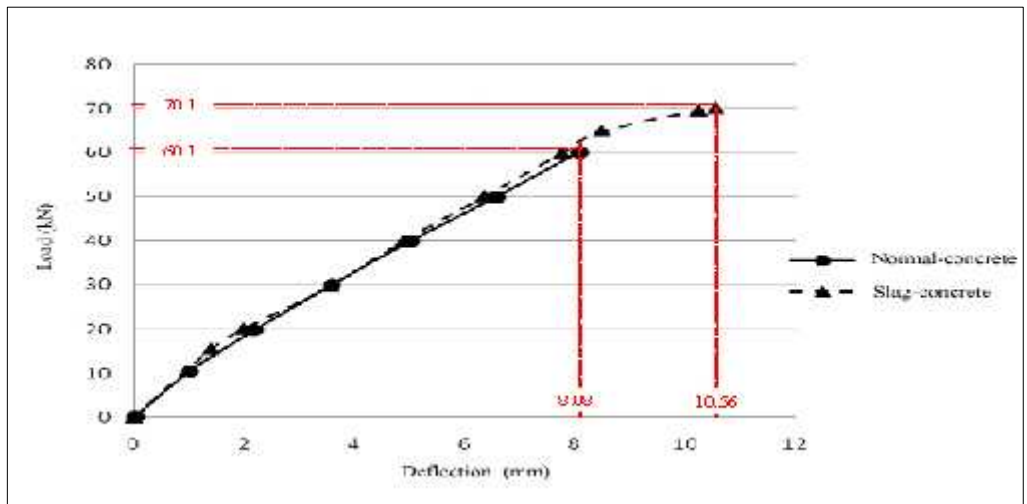


Figure 4. Load-deformation response of specimens at failure

Table 1. Shear-strength capacity

Specimen	$P$ (N)	$f'_c$ (Mpa)	$\frac{P}{2 \cdot b_w \cdot d}$	$C$
Normal-concrete	60.100	45.677	1.58	4.29
Slag-concrete	70.100	49.919	1.84	3.84

The coefficient for *slag-concrete* is significantly lower than for normal concrete, leading to an 11% increase in shear strength.

The cracking pattern at failure is typical and can be observed in figure 5 and 6.

The cracks initiated at the support and propagated with an angle of  $45^{\circ}$  toward the points of loading. Although the cracks at the two ends did not start simultaneously, clear shear cracks were observed at the opposite ends of the major cracks.

The *slag-concrete* specimens exhibit not only a higher shear capacity, but also a better performance since its deflection at failure was 1.31 times that of the normal concrete beam. The *load-deflection* behavior is similar, having an elastic pattern up to 16% of the ultimate loading for the normal concrete beam, and 21% for the *slag-concrete* beam. Beyond the elastic range the curve follows a parabolic pattern till failure.

The *load-strain* relationship of the steel can be seen in figure 7. Based on the compatibility between the reinforcing steel and concrete at the corresponding fibers, the concrete strain response can be represented by the steel strain till the concrete tensile strength is reached. Beyond that point the behavior of steel will reflect the ductility of a member.

The strain readings reflect and confirm an increase in ductility, the steel strain at failure was 0.0016 and 0.0019 for normal and *slag-concrete* respectively. At this point the reinforcing steel has not reached the yield strain of 0.002.

## CONCLUSION AND RECOMMENDATION

The use of steel slag will improve shear capacity of concrete. At a 100% substitution of natural coarse aggregates with slag, an 11% increase in shear strength was observed.

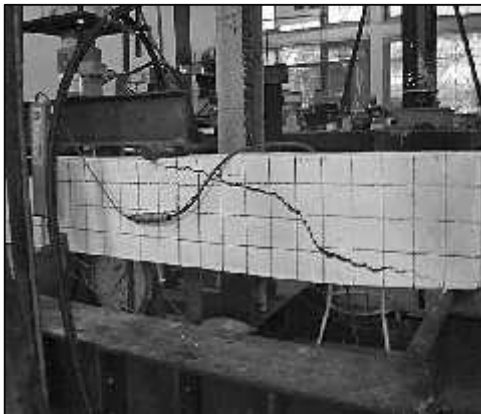


Figure 5 and 6. Normal and slag-concrete beam in shear failure

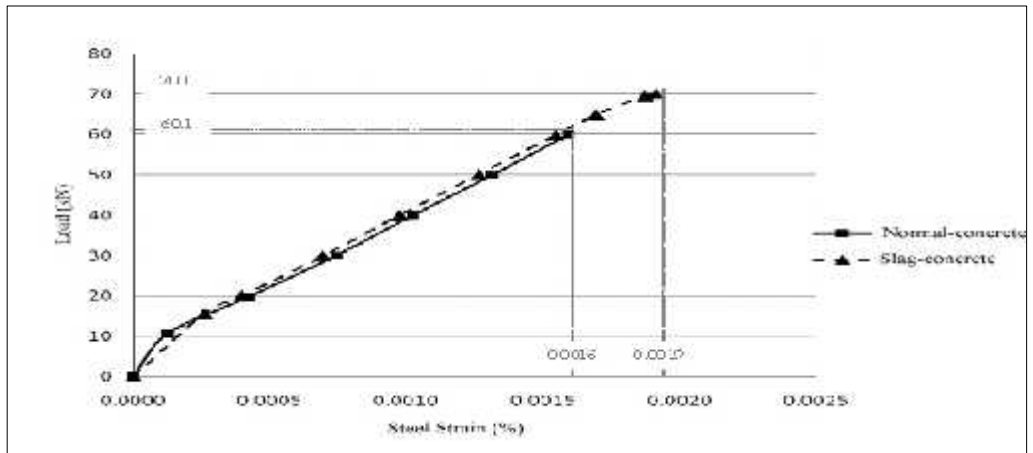


Figure 7. Load-strain relationship of tensile reinforcement

The failure mode and propagation pattern of shear cracks were not influenced by the slag use, the overall load carrying capacity of test specimen increased by 16.64%. This was a contribution of compression strength, shear capacity and probably bond strength increase.

Slag aggregates influence the ductility of elements in bending positively, both vertical displacement and strain measured at reinforcing steel levels showed an enhancement.

Further research work would be required to give a better understanding of the slag-concrete mechanical behavior. The effect of slag to the bonding of steel reinforcements has to be investigated as an individual phenomenon.

In general, the use of slag as a substitute to natural aggregates is promising, the decrease in soil and ground water pollution plus the reduction in use of natural stones will

support the national nature conservation program.

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