Steel-Slag as Aggregate Substitute's Influence to Concrete's Shear Capacity
An Experimental Approach

Han Ay Lie and Moga Narayudha

ABSTRAKSI

Penggunaan slag baja sebagai pengganti agregat kasar pada beton telah menunjukkan nilai-nilai positif seperti meningkatnya kuat tekan beton, perbaikkan 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 Pudak 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 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 Pudak Payung aggregates.

The experimental research shows that the slag-concrete's shear capacity increases 11% to the Pudak Payung concrete. The mode of failure however, remains the same.

Keywords: *slag, coarse aggregates, compression and shear strength.*

I. 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.

II. 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 obeserved by measuring the load, deflection and strain (figure 1).

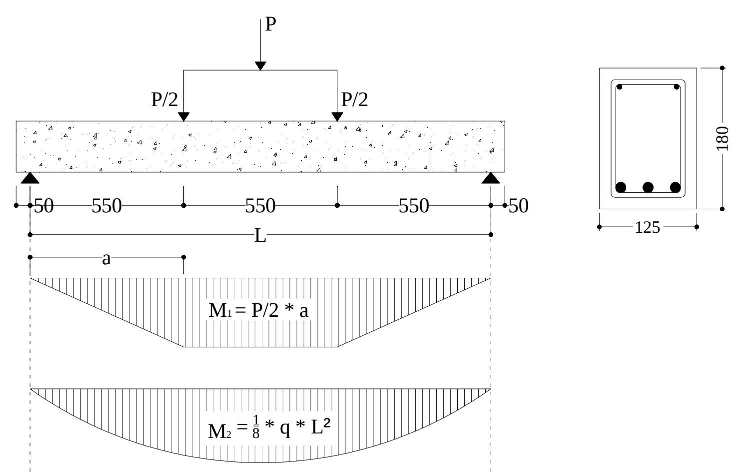

Figure 1. Schematic of tested beam

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^2. 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 (ρ_{max}) is 0.02845. The applied reinforcing steel is approaching ρ_{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 *Pudak 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).

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.

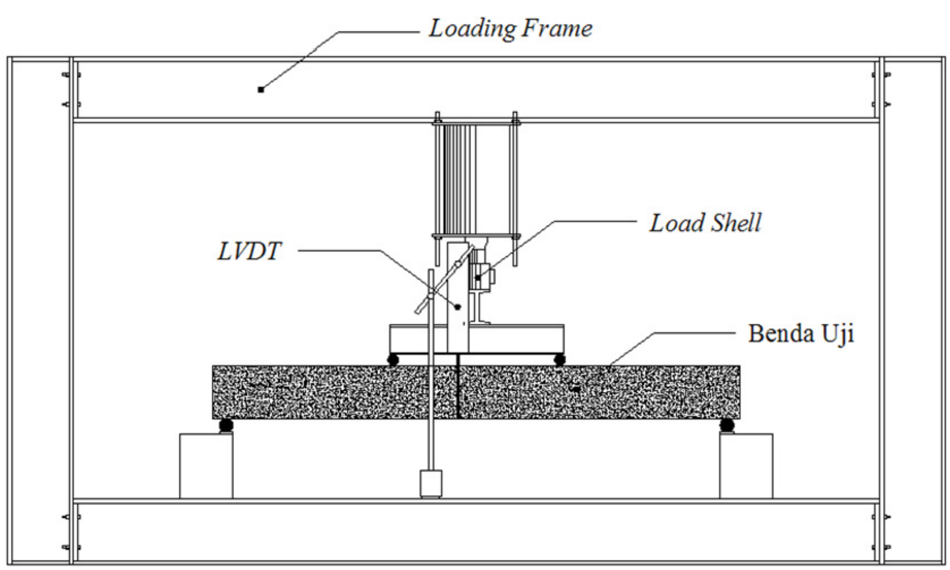

Figure 2. Test set up of specimen

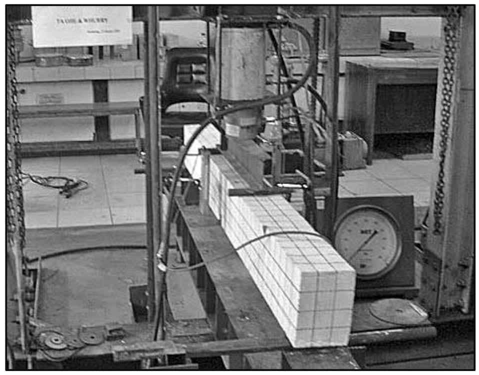

Figure 3. Beam specimen prior to loading

III. 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 week 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.

IV. 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.

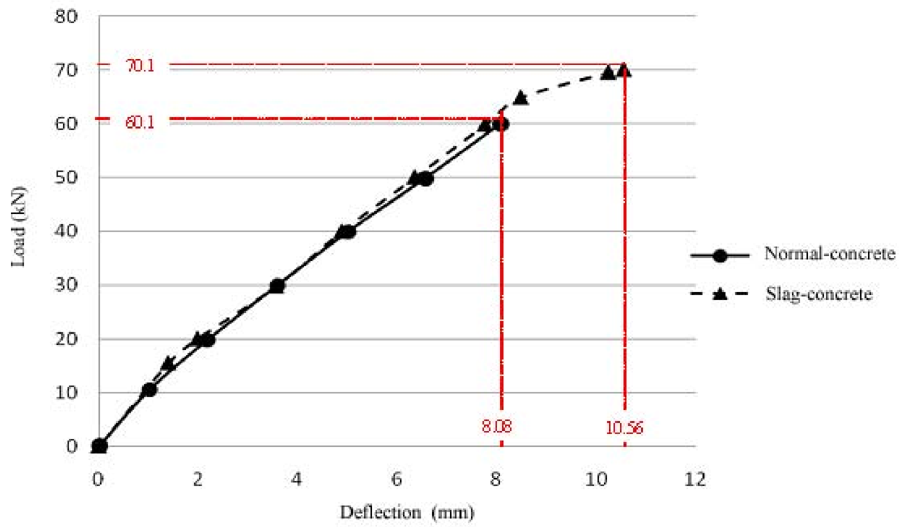

Figure 4. Load-deformation response of specimens at failure

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

$$v_c = \frac{1}{C}\sqrt{f'_c}$$

Where:

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

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

$$V_c = v_c . b_w . d$$

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):

Table 1. Shear-strength capacity

Specimen	***P (N)***	***f'c (Mpa)***	$\frac{P}{2.b_w.d}$	***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.

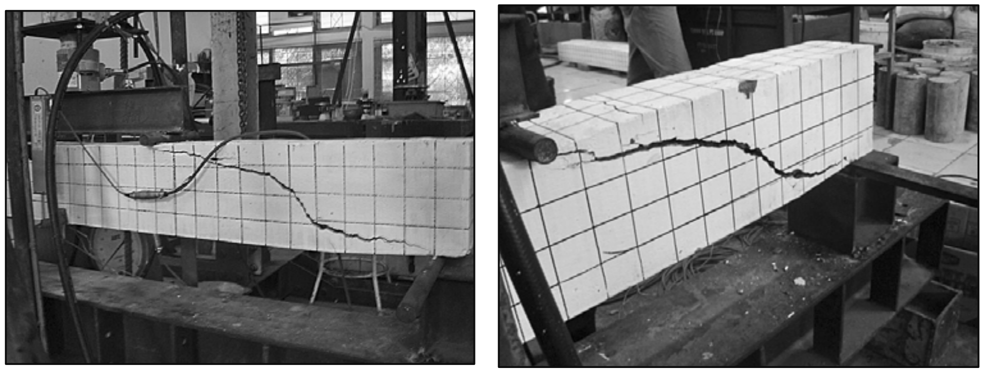

Figure 5 and 6. Normal and slag-concrete beam in shear failure

The cracks initiated at the support and propagated with an angle of 45^0 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.

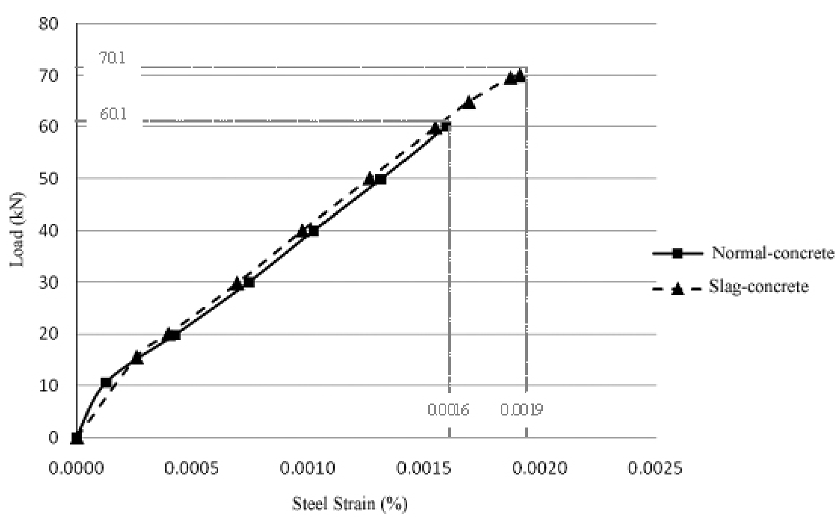

Figure 7. Load-strain relationship of tensile reinforcement

V. 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.

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.

Gratitude is expressed to PT Yaja Inti Steel, Semarang for their contribution in providing the slag, and to Ojie and Whurry who supported the overall laboratory work through their participation as research assistants.

VI. References

Bentur, A. and Alexander, M. G., 2000, "*A Review of the Work of the RILEM TC 159-ETC: Engineering of the interfacial transition zone in cementitious compositions*", Material and Structures, Vol. 33, March 2000, pp. 82-87

Besari, M.S., 2007. "*Review of Some Vital Physical Mechanical Parameters of Concrete*", International Conference on Material Development in the Concrete Industry, Jakarta, Indonesia.

Han A. L., and Tudjono S., 2008, "*The Study of Concrete with Industrial Steel-slag Aggregates based on the Substitution method*", 5th International Conference on Concrete, Singapore, August 2008.

Han, A. L. and Tudjono, S., 2007, "*PT Inti General Yaja Slag Replacing Pudak-Payung Aggregates for Concrete, an Experimental Research*". Proceeding of the National Seminar "Steel Development and Its Impact on Environmental Issues", Diponegoro University- AMBI (Indonesian Steel Community Association), Semarang, 23 July 2007.

Head, M.K., Wong, H.S. and Buenfeld, N. R., 2008, "*Characterising Aggregate Geometry in thin Section of Mortar and Concrete*", Cement and Concrete Research, Vol. 38 pp. 1227-1231.

Hsu, T. T. C., and Slate, F. O, Stuurman, G. M. and Winter G., 1963, "*Micro Cracking of concrete and the shape of the stress-strain curve*", Journal of the ACI Proceeding

Kurniawaty, I., 2006, "*Pemanfaatan Limbah Slag yang Mengandung Cr dan Zn dari Industri Baja dengan Metoda Solidifikasi sebagai Campuran Beton untuk*

Mengurangi Resiko Pencemaran Lingkungan" (Solidification of Cr and Zn containing slag waste as a concrete component to incorporate their environmental impacts), Thesis, Environmental Engineering Department, Diponegoro University, Semarang.

Leonardo, K., Pramono A., Rike, I. and Tirta A., 2008, *"Experimental Research for the use of Coarse and Fine Slag Aggregates in Concrete"*, Thesis, Material and Structural Laboratory, Diponegoro University, Semarang, Indonesia.

Mehta, P. K., 1986, *"Concrete: Structures, Properties and Materials"*, Prentice Hall

Mindess, S., Young, J. F. and Darwin, D., 2003, "*Concrete"*, Second Edition, Pearson Education Inc, Upper Saddle River, NJ.

Neville, A., 1997, "*Aggregate bond and modulus of elasticity of concrete"*, ACI Material Journal January-February 1997, pp 71-97.

Neville, A., 2003, "*Properties of Concrete"*, Fourth Edition, Prentice Hall, New Jersey.

Perry, C. and Gilliot, J.E., 1977, *"The influence of mortar-aggregate bond strength on the behavior of concrete in uniaxial compression"*. Cement and Concrete Research Vol. 7

Purwono, L. A. and Nurhayanti, S., 2007, *"Tinjauan Eksperimental Kuat Tekan Beton Dengan Campuran Limbah Slag" (Experimental study for determining the compression strength of concrete using slag waste),* Thesis, Civil Engineering Department, Diponegoro University, Semarang.

Putra, V. S. and Nurhidayati, Z. A., 2006, "*Penelitian Pemanfaatan Limbah Padat Sebagai Agregat Kasar Pada Beton" (Solid steel waste as coarse aggregate for concrete, and experimental study),* Thesis, Civil Engineering Department, Diponegoro University, Semarang.

Rao, G.A. and Prasad, B.K.R., 2002, *"Influence of the Roughness of Aggregate Surface on the Interface Bond Strength",* Cement and Concrete Research, Vol. 32 pp. 253-257.

Shofianto and Sutrisno, U. W., 2007, *"Pemanfaatan Slag Limbah Baja untuk Campuran Beton",* Thesis, Civil Engineering Department, Diponegoro University, Semarang.