IMPROVEMENT OF BASE AND SUB-BASE SOIL USING STEEL SLAG

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The improvement of engineering properties of base and sub-base course soil was investigated and studied using steel slag material. For this purpose, an experimental program was developed and performed to investigate the improvement of shear strength and California bearing ratio (CBR) of base soil materials by adding variant percentages of steel slag. The testing program were designed depending upon maximum dry density, $\gamma_{dmax.}$, and optimum moisture content, OMC. In addition to that, a field performance was tested and investigated for the treated base soil of a road section of 100 m long and 3.5 m wide. The results of laboratory tests showed that: (a) the values of CBR and shear strength have a considerable increasing when coarse soil-steel slag is used by 20% to 30%; and (b) the values of CBR are greater than that of non-treated base coarse soil when coarse soil-steel slag is used by 20% to 30%. Additionally, the field plate loading test results indicated that the vertical deformation (settlement) and permanent deformation of the treated base course is less than that of non-treated base course.

Keywords: Base material, steel slag, soil improvement, CBR

1 Introduction

The underlying soil that has a marked and sustained resistance under load application whether is wet or dry is called a stable soil. When the soil is treated to improve its strength and resistance to deformation, it is said to be a stabilized soil. So, the soil stabilization is the treatment of natural soil to improve its engineering properties. Stabilization or/and improvement of soil engineering properties is made by mechanical, chemical, thermal or electrical means, Saad et al. (1995). In road construction, stabilized soils may be used in: (a) surface or wearing courses for light traffic road especially in stage construction where pavement is to be constructed as the traffic increases; (b) base courses under a wearing surface subjected to medium or light traffic; and (c) sub-bases or improvement of existing sub-grade soil in order to obtain high type pavements carrying heavy traffic (Saad et al. 1995, Marandi and Safapour 2009, Tamadher et al 2007, Spangler and Handy 1973).

The use of stabilized bases in flexible pavement structures has increased steadily over the past decade. Many countries spend several billion dollars annually to repair and maintain distress roads, and other structures built on the weak soils Marandi and Safapour (2009) and Tamadher et al. (2007). Therefore, stabilization of the aggregates and soils is primarily used to improve the engineering properties of pavement materials. In many areas, the supply to high quality aggregates is becoming depleted requiring engineers to advantageously use stabilization techniques to improve the aggregates, substandard aggregate and recycled aggregate. The most commonly used stabilizers are lime, cement and fly ash Saad et al (1995) and Assa'd and Shalabi (2004). Various levels of stabilization occur when lime, cement and /or lime fly ash is added to the soil or aggregate. Depending on the level of stabilization, the final result could be anywhere from improving the inter particle binder matrix interaction to develop a stiff cemented layer within the pavement. Performance of these pavements depends on the long-term deterioration of the materials under environmental and load related factors Hall et al (2012) and Nuno et al. (2012).

Many studies have been performed to improve the engineering properties of earth materials. Some of these studies used additives (admixtures) such as lime, cement, fly ash, calcium chloride, olive waste, asphalt, while, others used geosynthetic materials and compaction to improve soil properties (Assa'd and Shalabi 2004, Hall et al. 2012, Nuno et al. 2012, Kumar and Sharma 2004, Azzam 2014). Assa'd and Shalabi (2004) studied the effect of of adding fly ash, cement and lime on the strength of a high plasticity clayey soil. The results indicated that the soil strength increased as the soil mixed with fly ash in addition to lime or cement. Also, Kumar and Sharma (2004) stated that adding fly ash to clayey soil reduced the soil plasticity, permeability and swelling characteristics, while, un-drained shear strength is increased.

The effect of adding cement dust, copper slag, slag-cement, and granulated blast furnace slag on the swelling behavior of expansive soil was studied by Al-Rawas et al. (2002) and Al-Rawas (2002). The results agreed with other studies and showed that the swell pressure and swell percent of treated soil are decreased due to particle aggregation. Additionally, many of recent studies support and agree that the increase in the percent of fly ash and curing time decreased the swelling potential, activity and plasticity of the treated soil. Also, the use of granulated blast furnace slag in the presence of an adequate amount of lime or burned olive waste or cement to expansive clay caused a reduction in swelling characteristics Nuno et al. (2012).

Azzam (2014) was illustrated the application of using polymer stabilization in creating a new nano-composite material with clay soil. Various tests with different polymer contents were performed to study the effect of using polypropylene as a stabilizing agent on both microstructure and geotechnical clay properties. These experiments showed that the resulting nano-composites acted as nano-filler materials which decreased the plasticity and compressibility parameters of the treated clay. The initial structural analysis helped in a better understanding of the modified microstructure and the measured size of induced nano-composites. Also, he added that, the constructed inclusions filled the inter-assembling pores thus notably producing a higher vertical effective yield stress which again reduced the volumetric shrinkage and created isotropic and compressible materials with a lesser extent of desiccation cracks. It also increased the tensile and the shear strength of the stabilized clay with an increase of the nano-composite size. This technique can be effectively used for road embankments and slope stabilization.

The objective of this study is to investigate the use of by-product steel slag aggregates (SSA) as a stabilizer or/and improving material. The investigation focuses on the engineering properties of limestone as base and sub-base course materials mixed with steel slag aggregate (SSA). Then, the effect of steel slag aggregates on shear strength, CBR and deformation of the improvement base course materials were studied and investigated at $\gamma_{dmax.}$ and OMC.

2 Used Materials

2.1 *Base course material*

The base course material used in this study was obtained from one of the quarries located in the south of Riyadh city, Saudi Arabia. The aggregates were limestone with liquid limit (LL) 34%, plasticity index (PI) 11% for fine aggregate portion and specific gravity (G_s) 2.67 for coarse aggregate portion. Depending upon unified soil classification system (USCS), the base course soil is classified as GP-GM (poorly graded gravel with non-plastic fines) as indicated in grain size distribution curves, Figure 1.

2.2 *Steel slag aggregate*

The steel slag aggregates (SSA) were obtained from Steel Product Company Limited (SPCL), Olayan group, in Riyadh, Saudi Arabia. Where, large quantities of steel slag are produced daily from steel manufacturing (about 75 tons/day). This material is dumped randomly in open areas and it is expected to have a harmful impact on the environment if not disposed properly. Grain size distribution curve of steel slag aggregate is shown in Figure 1 and the steel slag is classified as GP (poorly graded gravel) as USCS. The aggregates passing 38.1 mm (1.5") sieve were used in this study. The specific gravity (G_s) was 3.15 for steel slag aggregate.

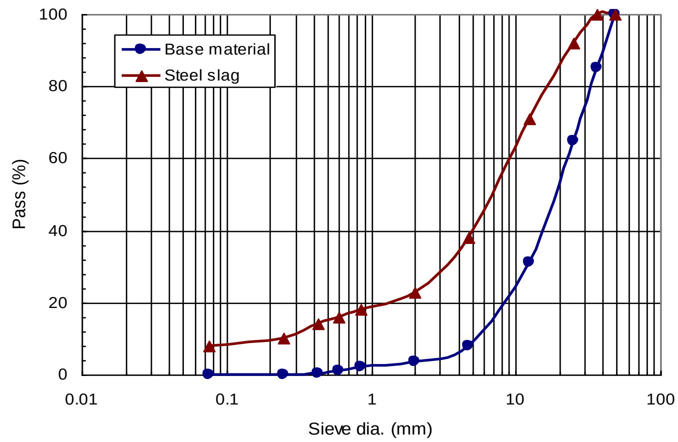

Figure 1: Grain size distribution of the used materials

3 Testing Program

To achieve the objectives of this study, a testing program was designed to investigate the behavior of the treated base-coarse material, as shown in Table 1. It clear that laboratory tests included modified compaction, large scale unconfined compressive strength, large scale direct shear and California bearing ratio (CBR) were performed at different percentages of steel slag ranging between 0-50%. The steel slag materials were added to the base course at optimum moisture content (OMC) and maximum dry density ($\gamma_{dmax.}$). Where, OMC and γ_{dmax} were determined from Modified Proctor Compaction test. Additionally, plate loading tests in the field were carried out using bearing plate of 300 mm diameter to investigate the effect of steel slag on the behavior of treated base coarse layer.

Table 1: The testing program of base-coarse material

Tests		Steel slag content (%)					
		0	10	20	30	40	50
Laboratory	Sieve analysis	√	√	√	√	√	√
	Modified compaction	√	√	√	√	√	√
	Unconfined compressive	√	√	√	√	√	√
	Direct shear	√	√	√	√	√	√
	CBR	√	√	√	√	√	√
Field	Plate bearing	√		√	√		

4 Results and Discussion

4.1 *Laboratory works*

Grain size distribution curves were developed at different percentages of steel slag, as shown in Figure 2. The mixes between steel slag and base soil were designed. So that the grain size distribution curves are bounded by the upper and lower gradation limit curves suggested by the Ministry of Public Works (MPW) in Saudi Arabia for highway pavement structures. Also, limestone mineral filler (material passing sieve # 200) was used to provide some plasticity to the mixes. Accordingly, grain size distribution curves of the treated base materials are highly agreed with the base materials suggested by MPW.

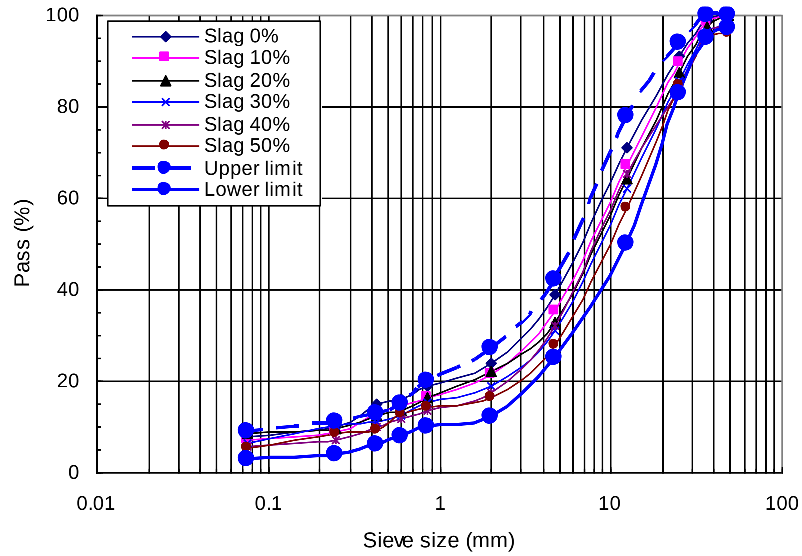

Figure 2: Grain size distribution of the base material with different steel slag content

4.1.1 *Optimum compaction*

Modified Proctor compaction curves were developed at different percentages of steel slag aggregate, as indicated in Figure 3. Also, The obtained values of compaction parameters (OMC and γ_{dmax}) are tabulated in Table 2. Referring to the obtained results, it can be seen that the maximum dry density increases with the increase of steel slag content. In addition, there is a change in the OMC as the steel slag increases. For instant, the base material treated with steel slag content 50%, the value of γ_{dmax} increases by about 23% more than that of non-treated base material, while, OMC value decreases by about 50%.

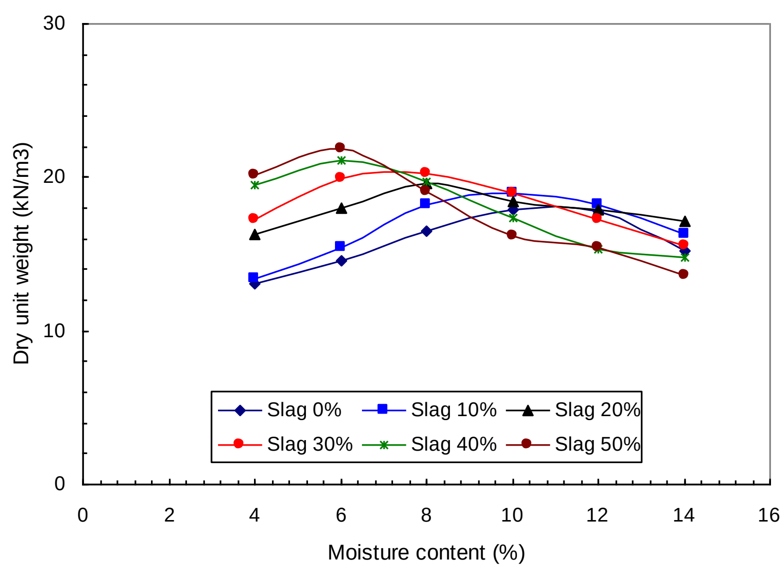

Figure 3: Compaction result curves of the studied base material with different steel slag content

Table 2: Modified compaction results

Tests	Steel slag content (%)					
	0	10	20	30	40	50
Max. dry density (γ_{dmax}), kN/m^3	18.4	19.2	19.8	20.4	21.5	22.6
OMC (%)	10.5	9.8	8.2	7.5	6.4	5.2

4.1.2 *Unconfined compressive strength*

Unconfined compression tests were conducted on relatively large cylindrical samples (10 cm in diameter and 20 cm in height) of the treated base coarse material. The results in Figure 4 show that the compressive strength of the treated base coarse increases from 62 kPa at 0% steel slag content to a maximum values of 182 kPa and 178 kPa at 20% and 30% steel slag content respectively, after that, the strength decreases with the increase in steel slag content. The decrease in strength beyond 30% steel slag content is attributed to the non cohesive nature of steel slag.

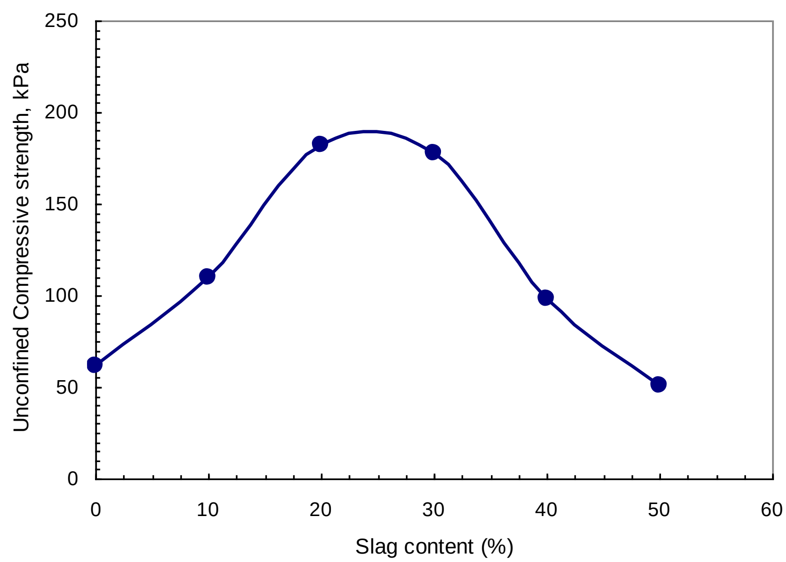

Figure 4: Unconfined compressive strength of the studied base material with different steel slag content

4.1.3 *Direct shear*

Large scale direct shear tests (25 cm x 25 cm cross sectional area) were conducted on treated base course material. Special device was designed and manufactured for these tests, as shown in Figure 5. Consolidated untrained (CU) tests were performed at optimum conditions of the treated base coarse material. The obtained results are shown as shear strength failure envelopes. Figure 6 shows the obtained results from the large scale direct shear tests for the samples prepared at the optimum conditions of the corresponding steel slag content compaction curves. The results show that the highest failure envelopes are achieved at 20% and 30% steel slag content. While, the failure envelopes at steel slag content of 40% and 50% are lower than that of 0% steel slag content.

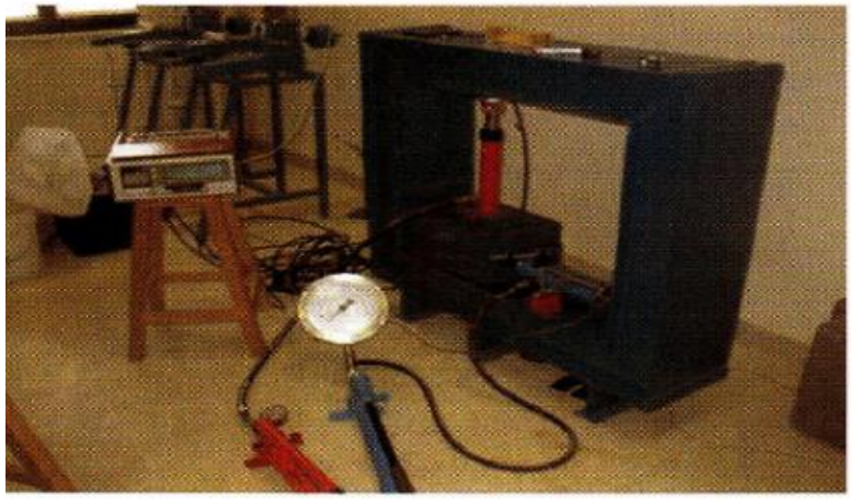

Figure 5: Large scale direct shear device

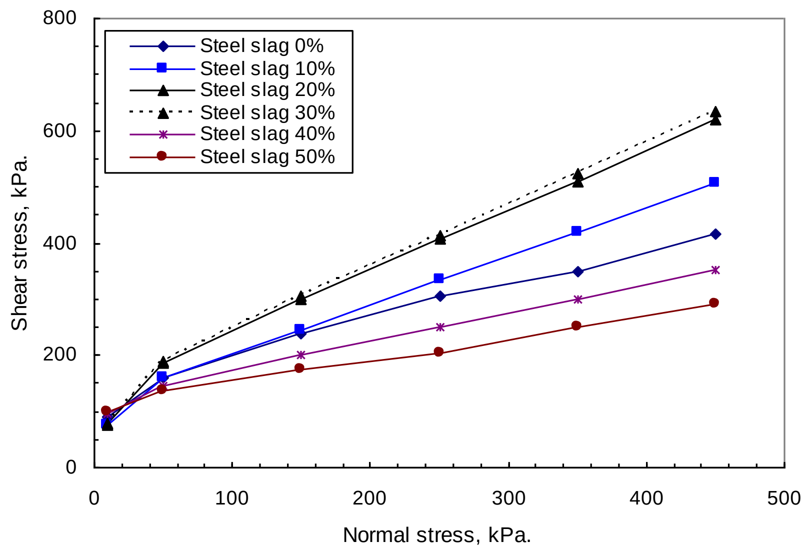

Figure 6: Shear strength failure envelopes for the studied base material with different steel slag content

4.1.4 *California Bearing Ratio (CBR)*

Soaked CBR tests (samples were emerged in water for 96 hours before testing) were conducted on the treated base course material. The results of CBR tests, in Figure 7, indicate that the soaked CBR value increases with the increase in steel slag content and it reaches a maximum value at a steel slag content of 20% and 30%. Then, CBR value decreases with the increase in slag content. The results show that replacing 20%-30% of base course materials by steel slag coarse aggregate increases the CBR value from 52 to about160 (more than three times increase). The trend of the CBR results is almost identical to the trend of the unconfined compressive strength results, see Figure 4. For more indication, Table 3 contains the values of unconfined compression strength and CBR values.

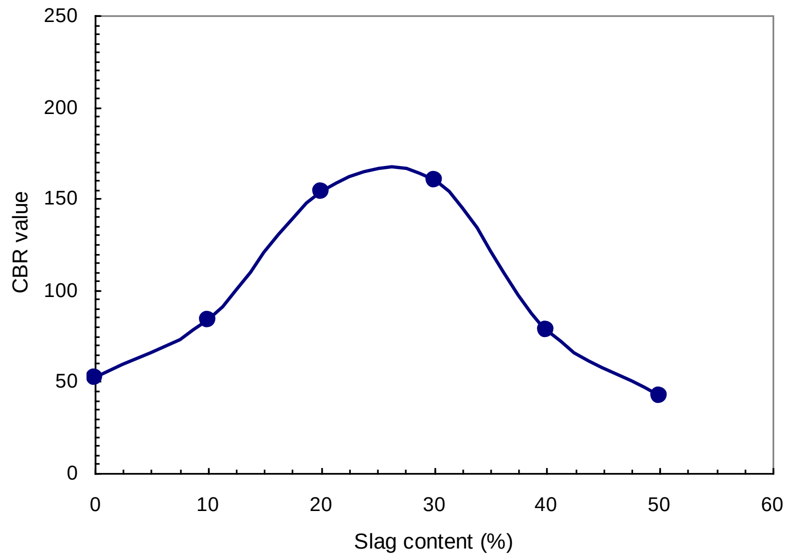

Figure 7: CBR values for the studied base material with different steel slag content

Table 3: Comparison between unconfined compressive strength and CBR values

Results	Steel slag content (%)					
	0	10	20	30	40	50
Unconfined comp. strength, kPa.	62	110	182	178	98	57
CBR, value	52	84	154	160	78	42

4.2 *Field works*

The tested road section was selected in the area of south Riyadh City, Saudi Arabia. The section is 3.5 m in width (one lane) and 100 m in length. Base layer of 15 cm in thickness was constructed at 3 section intervals of about 30 meters for each to consider the sequence of treated and non-treated base layer. Based on the laboratory work results as shown in Figures 3-7, 20% and 30% of steel slag content with 80% and 70% of lime base coarse material compacted at a water content of about 8.2% and 7.5% were used for the treated base layer sections. Where, Figure 8 shows the construction processes of the base layer for each tested road section.

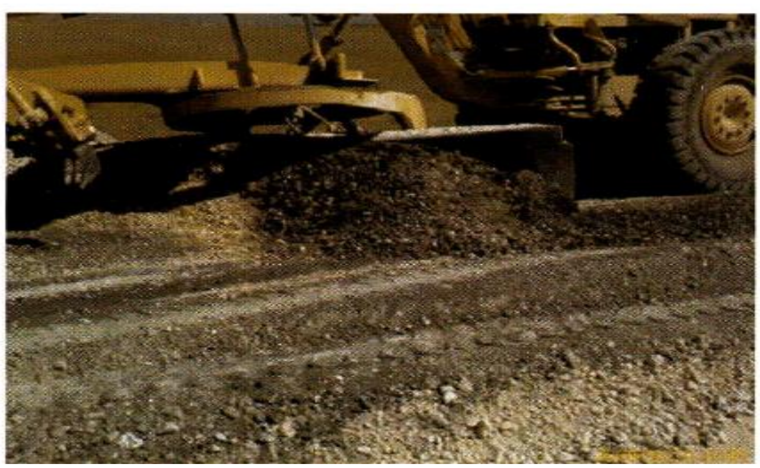

Figure 8: Field mixing of the studied base material with different steel slag content

After constructing the base materials, field density was determined using sand bottle and core cutter tests. The test results show that for the treated base course materials, the dry density and moisture content were 19.1 kN/m^3 and 7.8% respectively for 20% steel slag content, but, for 30% steel slag content, the dry density and moisture content were 19.8 kN/m^3 and 7.2% respectively. In the other side, for non-treated base materials, the dry density and moisture content were 17.7 kN/m^3 and 11% respectively. According to the measured values of field dry density and moisture content, it should be mentioned here that:

- The differences between OMC (10.5%, 8.2% and 7.5%) and the measured moisture contents (11%, 7.8% and 7.2%) for the non-treated layer, treated layer by 20% steel slag content and treated layer by 30% steel slag content, respectively, were very small (not more than 0.5%).
- The compaction factors for the treated and non-treated base material layers are more than 95% according to the suitable method of field compaction and good controlling of placing and compacting the base materials.

On the other side, plate loading tests were performed in order to investigate the effect of adding steel slag on the deformation characteristics of the base layers, as shown in Figure 8. The results of plate bearing tests of base layers are shown in Figures 9-13. Where, Figures 9 and 10 contains the plate loading results of base material of 20% steel slag content at first and second cycles of loading-unloading respectively compared with that results of non-treated base material, while, Figures 11 and 12 show that results of base material of 30% steel slag content compared also with non-treated base material. For more indication, Figure 13 represents first and second cycles of plate loading test for base material of 20% steel slag content compared with those cycles for non-treated base materials.

Fig. 8: Plate loading tests of the studied base material with different steel slag content

Referring to these figures (Figures 9-13), it can be seen that:

- At the first cycle and the same bearing pressure, the deformation (settlement) of the treated base layer is significantly less than that of non-treated base coarse layer. For example, at bearing pressure of 1000 kPa on base material of 20% steel slag content, the value of settlement is 2.4 mm, while, the settlement is 4.3 mm for non-treated base material. In general, the settlement for treated base material is decreased by about 45% less than that for non-treated base material.
- The results of plate loading test for base material of 30% steel slag content are approximately closed with the obtained results for base material of 20% steel slag content.
- At first cycle, the permanent deformations are significantly reduced by adding steel slag to the base layer. For instant, the permanent settlement for base material of 20% steel slag content is about 0.5 mm, while, the permanent settlement is 2.2 mm for non-treated base material.
- At the second cycle of loading-unloading, the permanent deformation for the non-treated base coarse layer was about 0.8 mm, while, for the treated base layer the permanent deformation was 0.45 mm

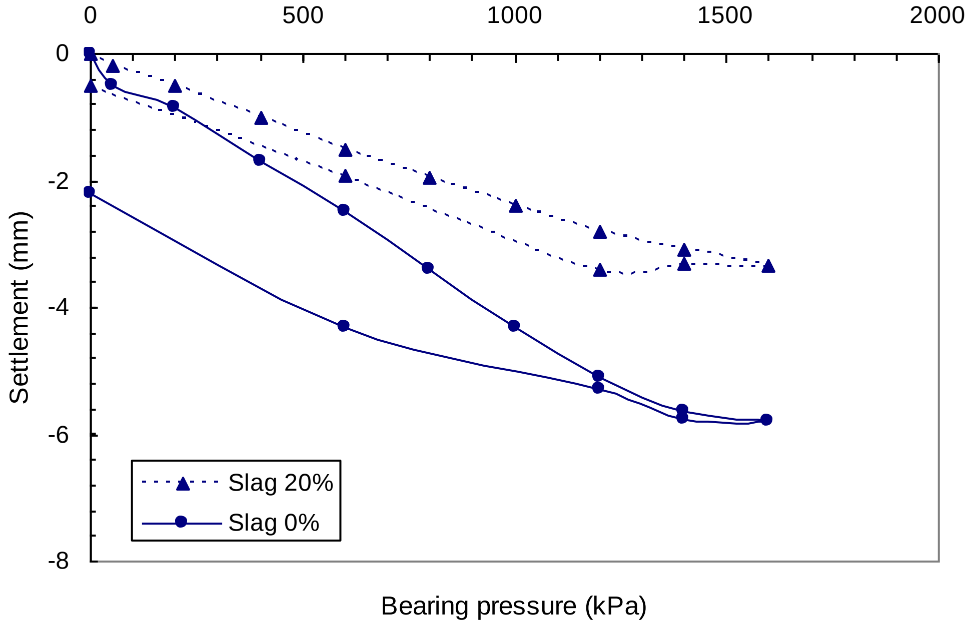

Figure 9: Plate loading test results for base material of 20% slag content compared with non-treated base materials (first cycle of loading-unloading)

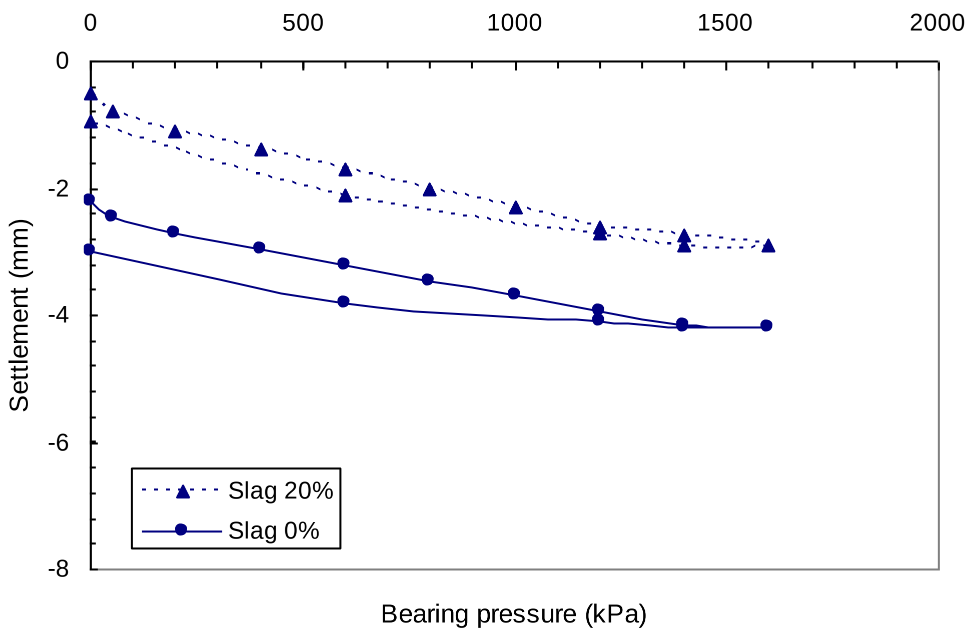

Fig. 10: Plate loading test results for base material of 20% slag content compared with non-treated base materials (Second cycle of loading-unloading)

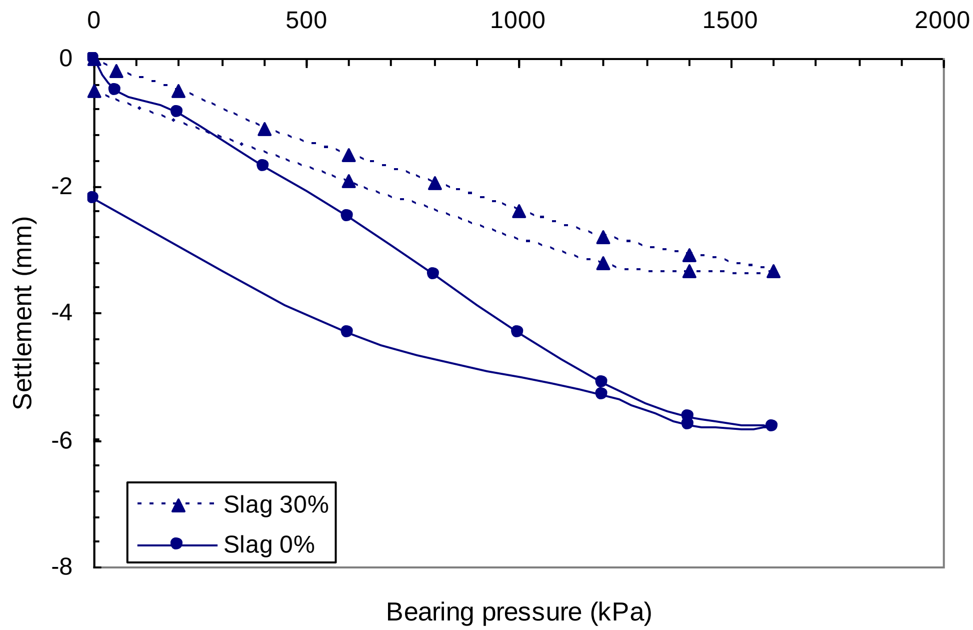

Fig. 11: Plate loading test results for base material of 30% slag content compared with non-treated base materials (First cycle of loading-unloading)

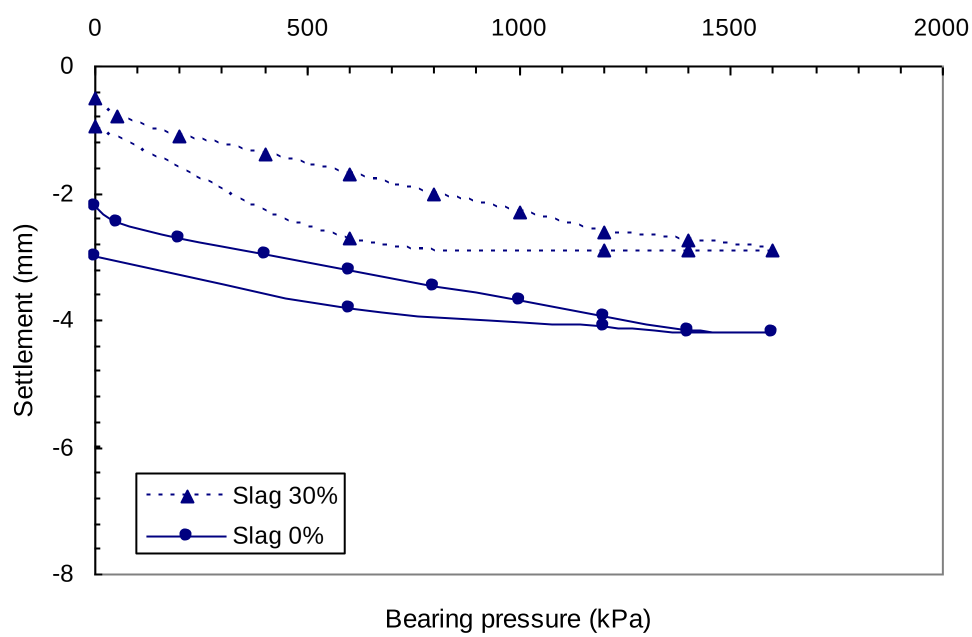

Figure 12: Plate loading test results for base material of 30% slag content compared with non-treated base materials (Second cycle of loading-unloading)

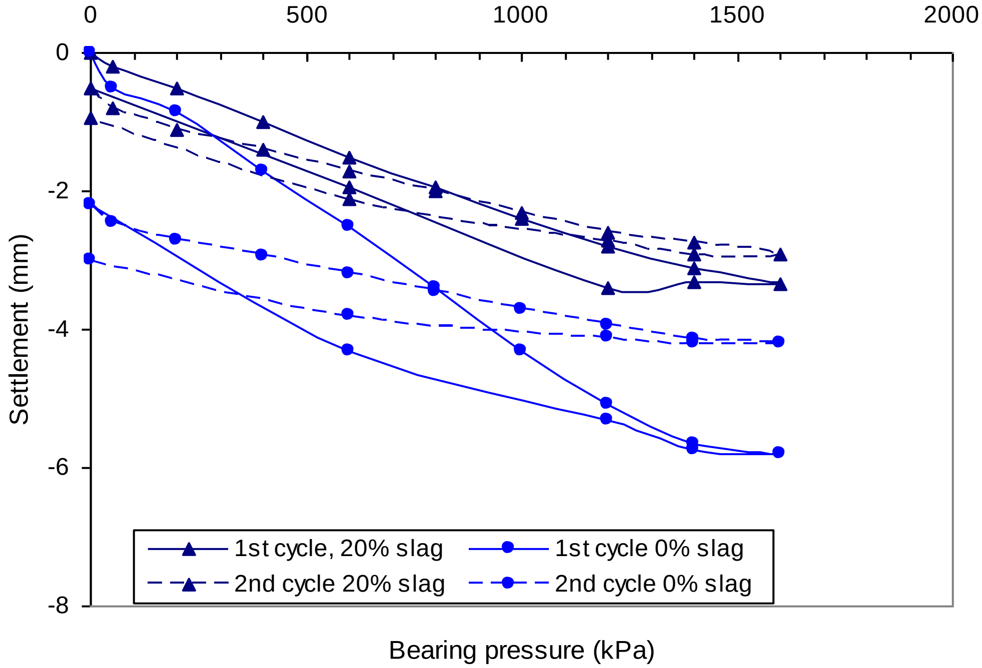

Figure 13: Plate loading test results for base material of 20% slag content compared with non-treated base materials (1st and 2nd cycles of loading-unloading)

5 Conclusions

An experimental program was conducted to investigate the effect of using by-product steel slag as a stabilizer for base course materials. In general, the results show that the steel slag can effectively be used to improve the engineering properties of base-course materials with awareness to the percentages that should be used. Specifically, the following conclusions can be drawn from this study:

1- Maximum improvement in shear strength and CBR values of the treated base material were achieved at 20%-30% of steel slag content. However, using steel slag up to 50% showed an improvement in compaction parameters ($\gamma_{dmax\ and}$ OMC).
2- The increase of steel slag content improves the dry density and compressibility of the treated base materials.
3- The bearing deformations (settlement) for treated base material are decreased by about 45% less than that for non-treated base material.
4- Permanent deformations for treated base material by adding steel slag are significantly decreased than that for non-treated base material.
5- It is important to perform large scale testing and field tests to include the effect of the course portion of the materials on behavior and engineering properties.

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