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Influence of Cooling Efficiency of Basic Oxygen Furnace Slag Used in Recycled Asphalt Mixtures

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Abstract: Basic Oxygen Furnace (BOF) slag is a by-product generated during the steelmaking process, a rapidly-developing heavy industry in Taiwan. Statistical data showed that approximately 120 million tons of BOF slag have been produced by China Steel Corporation each year. The by-product materials have generally been treated as waste and were buried in landfills, and have gradually become an environmental issue. Recent researches have shown that BOF slag could be used as substitute to aggregate, with different gradations, for producing asphalt concrete mixtures. The use of BOF slag as a pavement construction material not only could improve its economic value but also reduce the exploit of the riverbeds.

The use of recycled asphalt pavement (RAP) in asphalt pavement construction has been a common practice for many years. Researches showed that asphalt concrete containing RAP exhibited equal or better engineering properties as compared to conventional asphalt mixtures. However, very few researches have been devoted to the utilization of BOF slag in asphalt mixtures containing RAP.

The purpose of this study was to evaluate how various BOF slag contents in the asphalt mixtures with RAP would affect the mixtures' cooling rate at different stages, mixing, transport, pavement compaction, and after compaction. RAP asphalt mixture samples with 0%, 20%, 40%, 60% and 100% BOF slag as coarse aggregates were prepared. Temperature variations of the specimens were observed and recorded, and cooling rates were calculated during various stages of the mixing and construction processes. From the thermal properties of the mixtures, optimal time and temperature for opening to traffic of pavement containing BOF slag could be established.

Key words*: Basic Oxygen Furnace (BOF) slag; Cooling gradient; Indirect tensile strength, RAP mixtures (RAP).*

Introduction

Basic Oxygen Furnace (BOF) slag is a by-product generated during the steelmaking process, a rapidly-developing heavy industry in Taiwan. Statistical data showed that approximately 120 million tons of BOF slag have been produced by China Steel Corporation each year. The by-product materials have generally been treated as waste and were buried in landfills, and have gradually become an environmental issue [1-3]. The use of BOF slag as a pavement construction material not only could improve its economic value but also reduce the exploit of the riverbeds.

Recent researches have shown that BOF slag could be used as substitute to aggregate, with different gradations, for producing asphalt concrete mixtures. In their study, Xue *et al*. used BOF slag as aggregate in asphalt mixture and discovered that the surface texture of BOF slag was rougher than that of conventional aggregate and could increase the adhesion ability to asphalt binder [4]. Wu *et al*. stated that the porous structure of BOF slag could absorb the asphalt binder and would decrease permanent deformation of the asphalt mixtures at high temperatures [5]. A study by Maslehuddin's *et al*. showed that the use of steel slag in concrete could improve its compressive and tensile strengths in a higher degree compared to that incorporating limestone [6].

When used in porous asphalt, the incorporation of BOF slag could enhance its skid resistance, moisture susceptibility, rutting resistance and sound absorption [7]. Wu *et al*. also showed that the use of BOF slag could improve the high temperature property and resistance to low temperature cracking of Stone Matrix Asphalt (SMA) mixture [5].

The use of recycled asphalt pavement (RAP) in asphalt pavement construction has been a common practice for many years. Researches showed that asphalt concrete containing RAP exhibited equal or better engineering properties as compared to conventional asphalt mixtures [8-9]. However, very few researches have been devoted to the utilization of BOF slag in asphalt mixtures containing RAP.

According to specifications in Taiwan, pavements can not be opened to traffic until eight hours after completion of construction or until the pavement temperature drops below 50°C. However, in order to reduce the negative impact to traffic, especially in heavily trafficked metropolitan areas, asphalt pavements were often open to traffic before they could reach the required temperature. The characteristic of asphalt binder exhibits viscous-plastic behavior at higher temperature, and changes to viscous-elastic at room temperature, at which, tightly package with aggregate to gain strength gradually. When the pavements were open to traffic before cooling to desired temperature, where the asphalt mixture has not reached a stable condition, traveling by heavy vehicles could result in early damage to the pavement structures.

The maximum allowable temperature for asphalt mixture production has decreased gradually. At the same time, minimum temperature of 120°C needs to be maintained for adequate asphalt pavement compaction. For long-hauling distance and during winter

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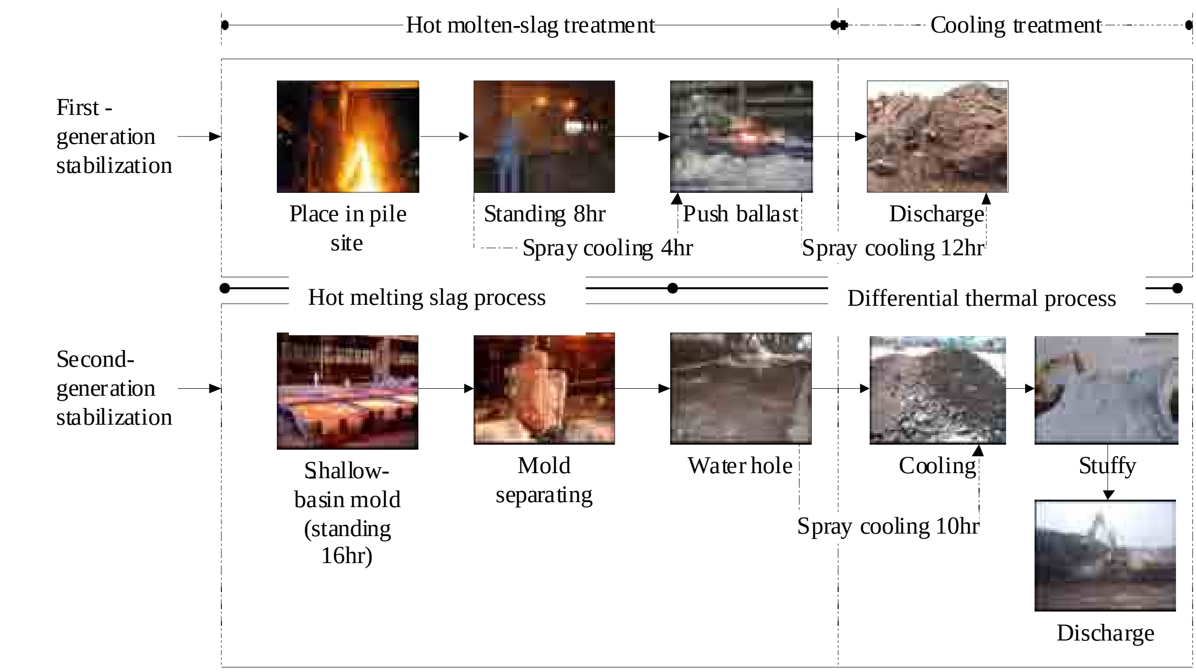


Fig. 1. Stabilization Procedure for BOF Slag.

times, slower cooling rate is desired to reduce the possibility of mix being too cold for compaction. On the contrary, it would be advantageous to have higher cooling rate after pavement compaction so that the pavement can be opened to traffic in shorter time duration.

The purpose of this study was to evaluate how various BOF slag contents in the asphalt mixtures with RAP would affect the mixtures' cooling rate at different stages, mixing, transport, pavement compaction, and after compaction. RAP asphalt mixture samples with 0%, 20%, 40%, 60% and 100% BOF slag as coarse aggregates were prepared. Temperature variations of the specimens were observed and recorded, and cooling rates were calculated during various stages of the mixing and construction processes. From the thermal properties of the mixtures, optimal time and temperature for opening to traffic of pavement containing BOF slag could be established.

Stabilization Treatment Process for Basic Oxygen Furnace Slag

One issue associated with the use of BOF slag is its potential of volume expansion because it contains f-CaO and MgO active elements. Therefore, BOF slag needs to be treated before its use. The conventional production process for BOF slag was derived from hot molten-slag materials, known as "Hot Molten Materials on the Ground" method. In this method, the by-product from the steel-making process, the molten materials at temperature of about 1,200°C were poured directly onto flat surface and stayed on the surface for about 6 to 8 hours under wet condition. The process was followed by two cycles of water spraying and then cooling for 4 to 6 hours for each cycle.

A newer and improved treatment procedure, consisting of agglomeration, cooling and disintegration, was used in this study. As shown in Fig. 1, this procedure includes the following steps:

1. Pour the hot molten materials into a shallow steel plate; let the materials cool for about 16 hours until the temperature dropping to 300°C at the surface of the materials and 600°C at the center of the materials. Since longer time has passed in this step, the resulting materials would be more stable and the materials tended to cluster.
2. Remove mold.
3. Pour the materials into cold water container and keep pouring cold water for about 10 hours. Because of the temperature differences between the materials and the cold water, the materials would disintegrate naturally.

The new stabilize method would produce more stable BOF slag, with lower flat and elongate (F&E) and close to 100% crushed surface.

Materials and Testing Program

BOF Slag, Reclaimed and Virgin Aggregate

The BOF slag and virgin aggregates (granite) were provided from a local asphalt plant, while reclaimed aggregates were obtained from RAP materials from road aggregate suppliers. The BOF slag was used as substitute of coarse aggregate. Gradations of the aggregates were prepared in accordance with ASTM D3515, Standard Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures. Gradations of the three aggregates are shown in Fig. 2. From Fig. 2, it can be observed that the maximum sizes for all three aggregates are 12.5 mm. Both the BOF slag and the reclaimed aggregate (RAM) have higher percentages passing the 12.5 mm and 0.95 mm sieves than those of virgin aggregate. Other the other hand, the percent passing #4 sieve for the BOF slag and the RAM are much lower that that of virgin aggregate. In general, during the manufacturing process of BOF, the particle sizes would be between 7 and 15 mm (Fig. 3). The BOF slag is finer than the coarser portion of the virgin aggregate.

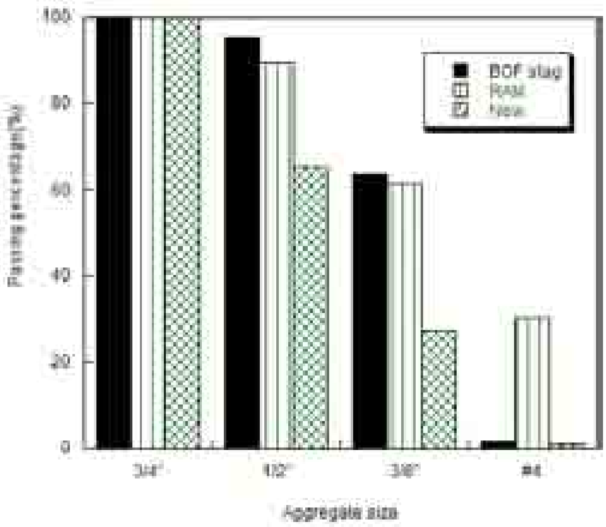


Fig. 2. Particle Size Distributions of BOF Slag, Reclaim and Virgin Aggregates.

Fig. 3. Particle Size Distribution of BOF Slag (7~15 mm).

The physical properties of BOF slag and virgin aggregate are listed in Table 1. Nominal maximum size for each aggregate is 12.5 mm. Test results indicated that BOF slag had higher specific gravity and water absorption, but lower L.A abrasion and Flat and Elongate (F&E) ratio than virgin aggregate. The specific gravities of BOF slag and virgin aggregate are about 3.4 and 2.6, respectively. As mentioned earlier, BOF slag is a by-product generated during the steelmaking process, and therefore contains higher amount of iron resulting in higher specific gravity. Furthermore, BOF slag has a more porous structure, showing higher water-absorption by about 2% over the virgin aggregate. BOF slag has really low values of LA abrasion and F&E ratio and close to 100% of fractured faces. These characteristics would provide strong aggregate interlocking and increase the resistance to aggregate breakdown when travel by heavy vehicles.

Physical Properties of Asphalt Binder

In this study, the RAP mixtures were obtained from a local aggregate supplier. Recycled asphalt binder was extracted from the RAP. AC-20 grade virgin asphalt cement was used. Table.2 lists the physical properties of AC-20 and recycled asphalt binders. As can be seen from Table 2, the recycled asphalt extracted from RAP has been slightly aged, with a Penetration value of 32.5 and a Viscosity value of 4,350 poise. These values were out of specification tolerance; however, the new asphalt binder also served as the softening agent for the recycled asphalt binders in the mixtures. With the use of RAP at 20%, this would not affect the property of the asphalt mixture.

Specimen Preparation and Testing

Mix design was developed based on Marshall Mix design method for heavy vehicle loads (75 blows on each specimen surface); to incorporate the use of RAP and BOF slag aggregates. The optimum asphalt contents in varies asphalt mixtures were determined in according to the Asphalt Institute method, MS-2. A recycling agent or softening agent has been commonly used to restore the aged bitumen to its original condition. The amount of recycling agent required was generally determined following ASTM D4887, utilizing the viscosity blending chart to determine the viscosity of the aged bitumen and the new asphalt binder. However, a National Cooperative Highway Research Program (NCHRP) study indicated that, for asphalt mixtures containing 15% to 25% RAP, the next grad of neat asphalt cement could be used as the softening agent [10]. The RAP content was fixed at 20% in this study; therefore, the AC-20 grade asphalt binder also served as the softening agent in this study.

The BOF slag aggregate was used to substitute portions of the coarse aggregate, while virgin fine aggregate was used. The percentages of the BOF slag used were 0%, 20%, 40%, 60% and 100% by volume of coarse aggregate, which corresponded to 0%, 12%, 27%, 42%, and 67% of total aggregate by volume, respectively (Table 3).

As mentioned previously, asphalt samples were prepared using Marshall Methods. Three samples were prepared for each of the mixtures, resulting in a total of 15 samples. The 15 samples were then heated to 120°C to simulate the asphalt mix temperature during asphalt paving; the samples were then allowed to cool and the rate of cooling were measured and recorded. Asphalt samples were also prepared for Indirect Tensile Strength Testing at temperature of 90°C, 80°C, 70°C, 60°C, and 50°C. Three samples were prepared and tested at each temperature. The test was performed to evaluate the performance of asphalt mixtures with different BOF slag contents at various temperatures during the cooling process.

Cooling Measurement

A 6 cm deep hole was drilled at the center of each asphalt

Table 1. Physical properties of BOF slag and virgin aggregate

Aggregate Type	Specific Gravity	Water Absorption（%）	L.A Abrasion （%）	Flat and Elongate （%）1：3 Above	Fractured Faces （%） Three or More
BOF Slag	3.40	2.61	13.24	0.9	96.20
Virgin Aggregate	2.61	1.76	28.00	9.8	54.30

Table 2. Physical Properties of Asphalt Binder.

Item	AC-20	Recycled Asphalt	Specification
Specific Gravity	1.034	1.046	－
Penetration （25℃,1/100cm ）	62.5	32.5	－
Softening Point (℃)	63	60	55-70
Viscosity（60℃, Poise）	1910	4350	＜2000
Ductility（25℃ ，cm）	100＋	80＋	＞50
Flash point（℃）	290	270	＞260
Toughness （25℃ ，kgf.cm）	369	250	＞80
Tenacity(25℃，kgf.cm）	145	120	＞40

Table 3. Aggregate Proportions by Volume of Total Aggregate.

Coarse Aggregate	Aggregate Proportions by Volume of Total Aggregate (%)			
	RAP (%)	BOF Slag (%)	Virgin Coarse Aggregate (%)	Virgin Fine Aggregate (%)
RAP 20% + BOF 0%	20	0	54	26
RAP 20% + BOF 20%	20	12	42	26
RAP 20% + BOF 40%	20	27	27	26
RAP 20% + BOF 60%	20	42	12	26
RAP 0% + BOF 100%	0	67	0	33

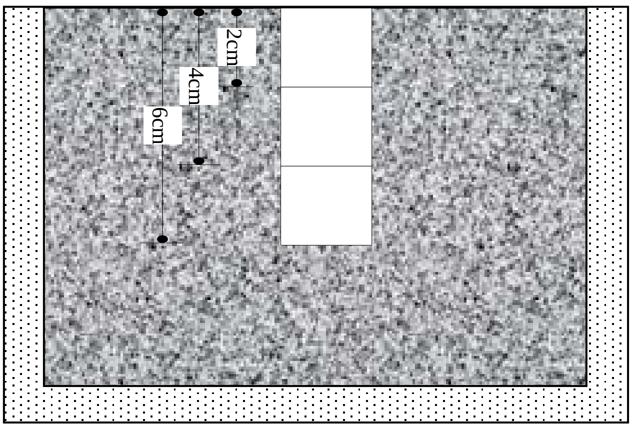


Fig. 4. Specimen Setup for Cooling Measurements.

specimen and thermal couples were inserted into the hole at four different depths, on the surface, and at 2 cm, 4 cm and 6 cm from top of the surface (see Fig. 4). The samples were placed in an oven and were heated to 120°C to simulate the asphalt mix temperature during asphalt paving. The specimens were then placed in insulation boxes to prevent heat loss caused by air movement and were allowed to cool down under room temperature. The CENTER309 temperature recorder was used in recording the temperatures. Temperatures were measured at 2.5-minute interval for all samples for 80 minutes. Three specimens were prepared for each type of mix and average values of the three samples were used in the following analyses and discussions.

Results and Discussions

The Effects of BOF Slag Contents on Specimen Cooling

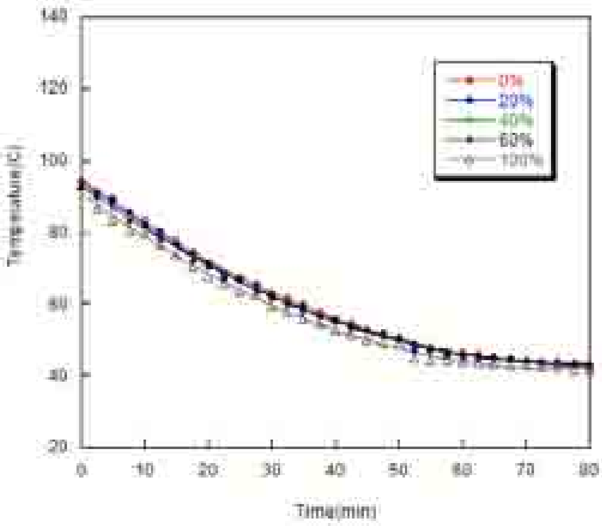
Fig. 5 presents the temperature variations with time at different depths in the specimens. From the Figure, it can be seen that on the surface, the curves representing temperature variations for mixtures containing different BOF slag are much tighter than those at a depth inside the specimens. The temperatures on the surface apparently were affected largely by the surrounding air temperature and the influence of the BOF slag content was relatively small. Also, temperature was about 120°C at the surface when they were removed from the oven and the room temperature was about 25°C. Since the surfaces were in touch of the air, temperatures dropped quickly, as shown in Fig. 5(a), with the starting temperature around 90°C. The temperatures at surface decreased quickly but stabilized after 30 minutes.

The influences of the BOF slag content on the temperature changes became more profound at depths inside the specimens, as seen in (b), (c) and (d) of Fig. 5. Since they were not in direct contact with the surrounding air, temperatures at the starting point were between 120 and over 130°C. For all three depths, at a particular time, the temperatures increased as the BOF slag content increased. Mixtures with higher BOF slag content seemed to hold heat better that those containing less BOF slags. At the end of measurements at 80 minutes, mixtures containing 20% of BOF slag or had reached a stable condition with temperatures between 45 and 55°C. However, mixtures with 40% of BOF slag or more still showed temperature decrease. The phenomenon indicated that it would required longer for mixtures containing BOF slag to lose heat and thus require more time the pavement could be open to traffic.

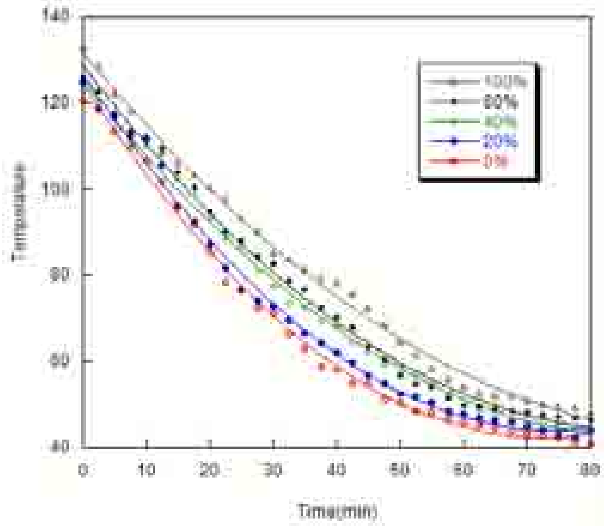
Analysis of Cooling Interval

In their study, Willoughby *et al*. defined the Cessation Temperature as the asphalt mixture temperature at which the density of asphalt pavement could not be improved with additional compaction effort [11]. Following this concept, the temperature-time curves for mixtures containing various BOF slag content in this study were divided into three zones, defined by the Initial Temperature, the Cessation Temperature, and the Equilibrium Temperature (opening temperature), as illustrated in Fig. 6. Temperatures corresponding to the three inflection points of the curve were defined as the three points.

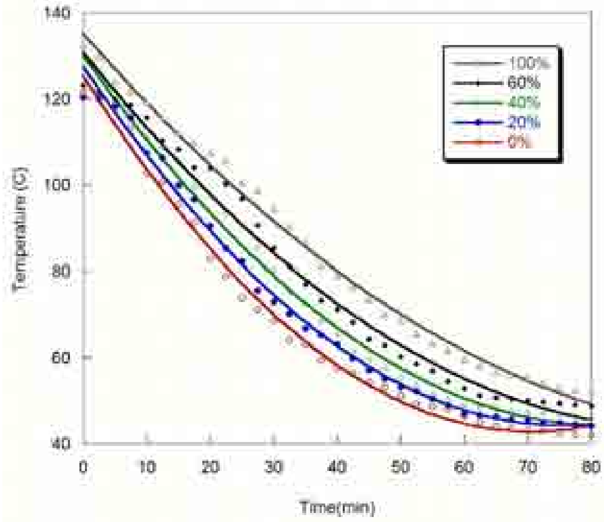
The Initial Temperature Zone represents the temperature changes from the time asphalt mixtures leaving plant to the time they were transported to the job site. The temperature change was the fastest within this time period. The temperature change slows down between the Initial Temperature and the Cessation Temperature. The mixtures reach a more stable state at the Cessation Temperature. At the Equilibrium Temperature, the asphalt temperature basically becomes a constant with very little change, indicating the proper time for opening to traffic. For normal dense grade asphalt the



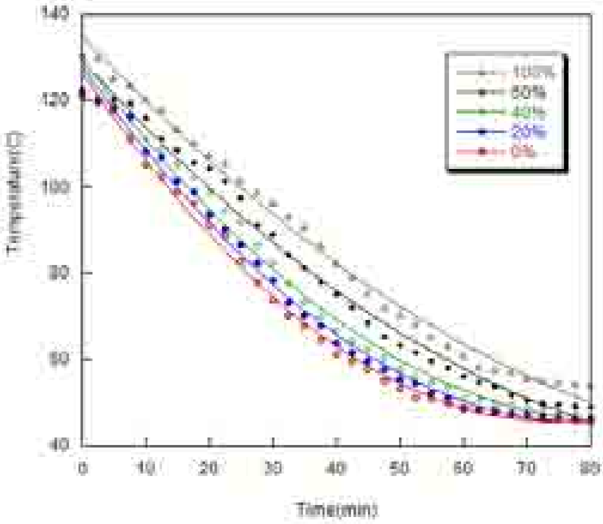
(a) 0 cm



(b) 2 cm



(c) 4 cm



(d) 6 cm

Fig. 5. Temperature vs. Time for Mixtures with Various BOF Slag Contents.

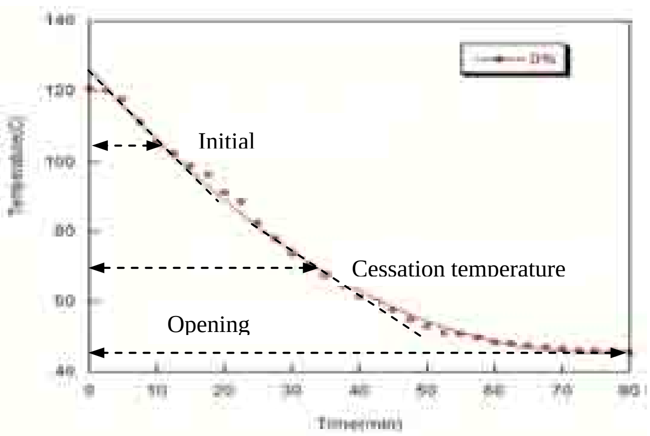
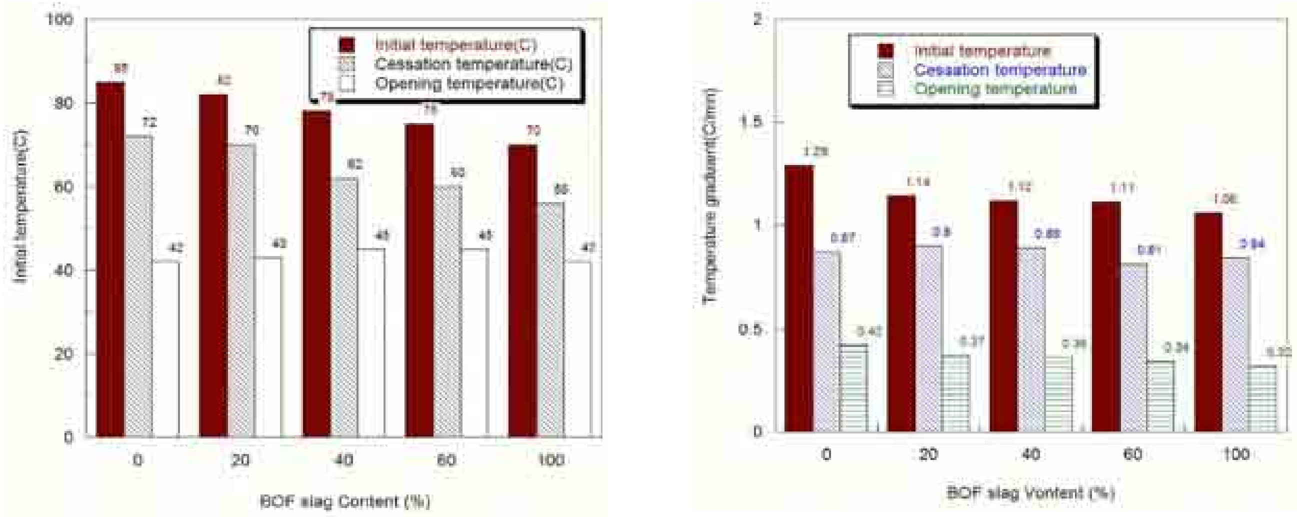


Fig. 6. Typical Cooling Interval Diagram of Asphalt Mixture.

the temperature is around 50°C.

The effects of BOF slag content on the cooling rate of the asphalt mixtures are shown in Fig. 7. From Fig. 7(a), it can be seen that the Initial Temperature and the Cessation Temperature decrease as the BOF slag content increases. For mixtures without BOF slag, the Initial and Cessation Temperatures are 85°C and 72°C, respectively; for mixtures with 100% BOF slag, the Initial and Cessation Temperatures drop to 70°C and 56°C, respectively. This phenomenon indicates that the BOF slag in the mixtures can help hold the temperature longer. Temperature becomes stable and heat release becomes slower at about 72°C for mixtures without BOF slag. For mixtures with 100% BOF slag, the temperature drops to 56°C. However, the use of BOF slag has little effect on the Opening Temperature, as the Opening Temperature are within 42 and 45°C for the mixtures.

In pavement construction, the compaction process consists of initial compaction, intermediate compaction, and finish compaction. The purposes of the initial compaction are to reduce voids; increase particle contacts; and make the mixtures into form. The initial compaction should be completed before moistures reach the Initial Temperature, such as the 85°C for the mixtures containing no BOF slag aggregates. The lower Initial Temperatures for mixtures with



(a) BOF slag Content vs. Temperature (b) BOF slag Content vs. Temperature

Fig. 7. Relationship between the Temperature Intervals and the BOF slag Contents.

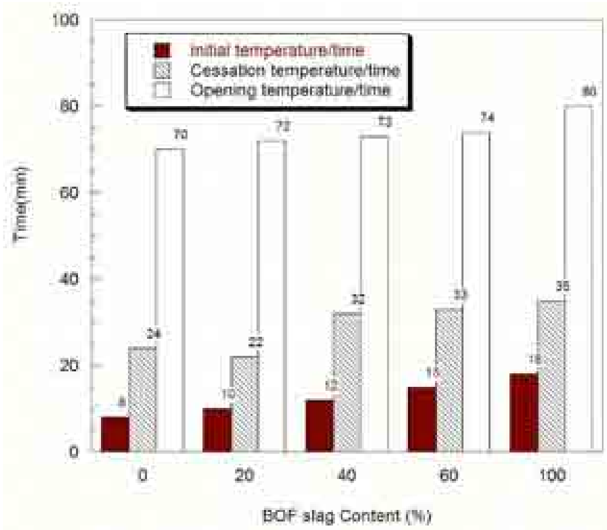


Fig. 8. Cooling Rate within Intervals.

BOF slag provide some benefits during winter construction, where lower pavement temperature can be tolerated. The required density of the pavements would be achieved during the intermediate compaction. The intermediate compaction needs to be completed before the Cessation Temperature. Again, the lower Cessation Temperatures of the mixtures with BOF slag provide more tolerance for completion of the intermediate compaction.

Time required to reach the three defined temperatures for mixtures containing various BOF slag aggregates are shown in Fig. 7(b). In the study, the oven temperature was set at 120°C. When the specimens were just taken out of the oven, the surface temperature drop quickly, from 120°C to 90°C in about 10 minutes. In general, a trend showing increasing time required to reach the Initial and Cessation Temperatures with increasing BOF slag content is observed. Time for reaching the Opening Temperatures also increases slightly as the BOF slag content increases; however, the differences are relatively small.

Cooling Rate within Intervals

To evaluate the effects of BOF slag content on the asphalt mixture cooling rate, the average cooling rate within the three temperature intervals are plotted vs. the BOF slag content, as shown in Fig. 8. Measured surface temperatures were used in this analysis. For the Initial Temperature Interval, the Initial Temperature was first subtracted from the temperature when the specimens were just removed from the oven. The result was then divided by the time period covering this interval. Cooling rates for the other two temperature intervals were computed similarly.

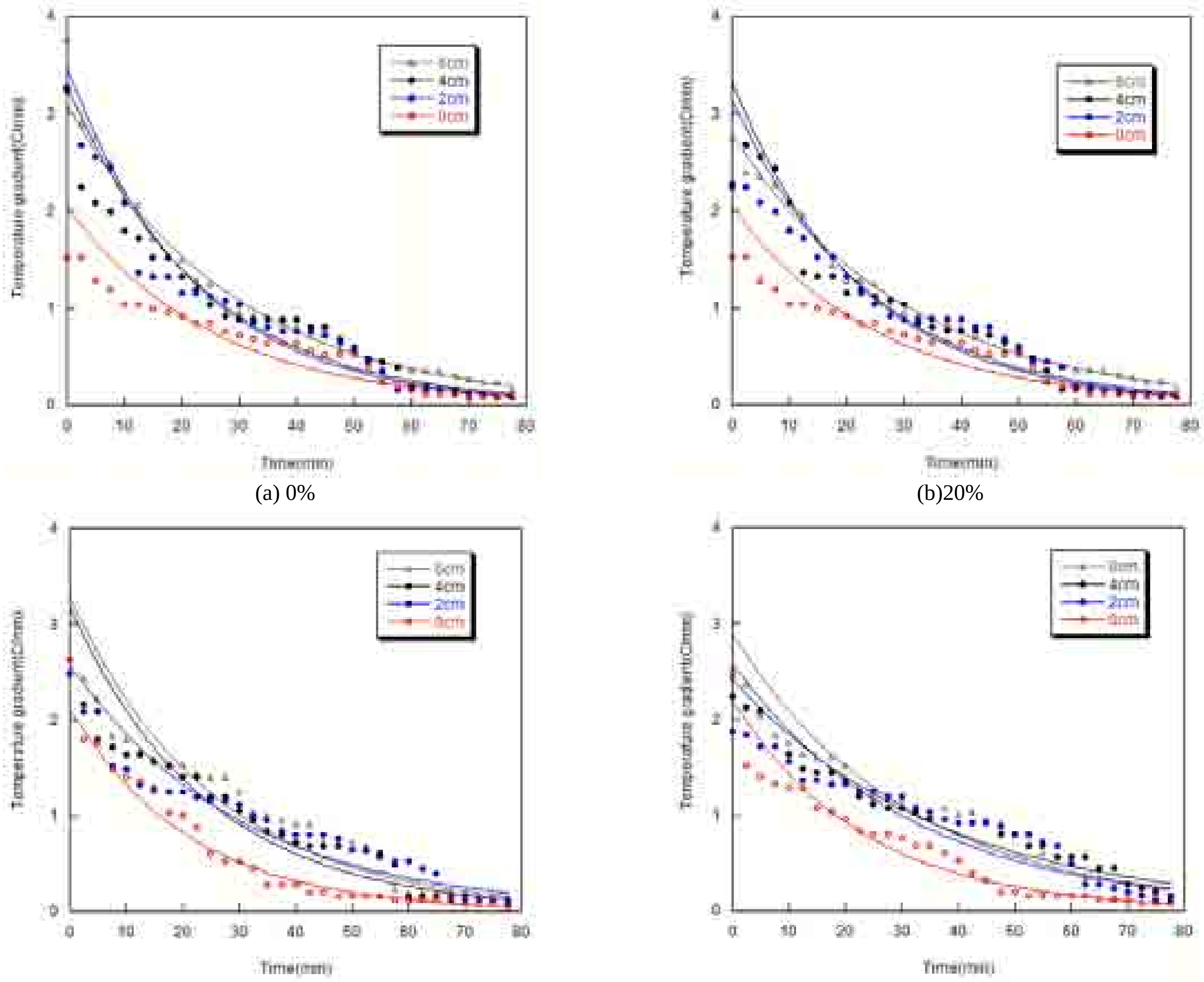
For the Initial Temperature Interval, a decreasing trend is observed as the BOF slag content increases. The average cooling rate is 1.29°C/min for mixtures without BOF slag; and the rate drops to 1.06°C/min for mixtures with 100% BOF slag. Similar trend is also observed for the average cooling rate within the Opening Temperature Interval. However, for the Cessation temperature interval, no clear trend can be observed.

Cooling Rate inside the Asphalt Specimens

The cooling rates at different depths of the various asphalt mixtures are analyzed. The changes of cooling rates with time for the asphalt mixtures containing different BOF slag contents are shown in Fig. 9. In Fig. 9, the cooling rate was calculated based on a time interval of 2.5-minute. As expected, the cooling rates decreases with time for all mixtures at all depths. It is somewhat interesting to note that, for all mixtures, the cooling rates on the specimen surfaces lower than those inside the specimens. The cooling rates at the 2 mm depth have the next lowest cooling rates. Cooling rates at the 4 mm and 6 mm depths are similar.

Effects of the use of BOF Slag on the Indirect Tensile Strength of Asphalt Samples

The effects of the use of BOF slag on the indirect tensile strength of asphalt samples were evaluated in this study. Asphalt samples were prepared in accordance with the procedures described earlier in this paper. Prepared asphalt samples with different BOF slag contents



(a) 0% (b)20%

(c)60% (d)100%

Fig. 9. Cooling Rates at Various Depths.

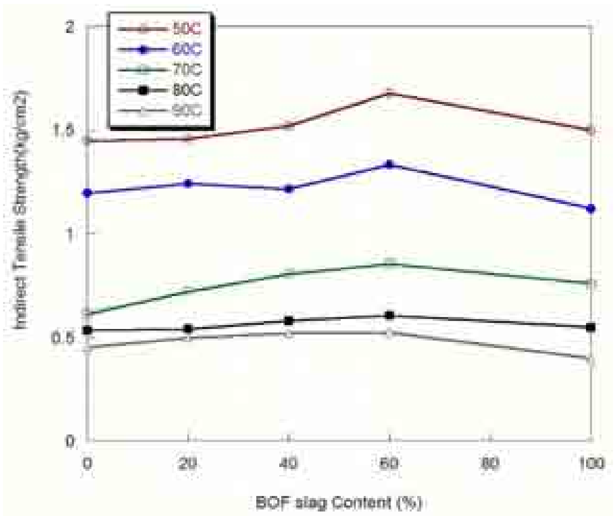


Fig. 10. Indirect Tensile Strength vs. BOF Contents at Various Temperatures.

The effects of the use of BOF slag on the indirect tensile strength of asphalt samples were evaluated in this study. Asphalt samples were prepared in accordance with the procedures described earlier in this paper. Prepared asphalt samples with different BOF slag contents were allowed to cool and were subjected to Indirect Tensile Strength Testing (ASTM D4123) at temperatures of 90°C, 80°C, 70°C, 60°C, and 50°C.

Test results are shown in Fig 10. As expected, for all asphalt samples, the indirect tensile strength increases as the temperature decreases. The asphalt samples do not gain sufficient strength until the temperature reaches 60°C. The indirect tensile strengths increase for about 100% when the temperature decreases from 90 to 60°C. The increase is about 150% when temperature drops from 90 to 50°C.

It is also noted that samples containing 60% of BOF slag show highest strengths at all temperatures; however, the increases are not significant. The increases become more noticeable at temperatures of 60 and 50°C. Because of the heavier unit weight, the use of BOF slag could increase the load capacity of pavement, to a certain degree. However, the differences in unit weight are significant; the use of higher percentage of BOF slag might affect the ability for the twp aggregates to interlock; and therefore, reduces their strengths. The aged asphalt cement contained in the RAP would also affect its

Table 4. Equation Parameter *A*, *B*.

t_d	$0\le t_d<5$	$5\le t_d<11$	$11\le t_d<24$	$0\le t_d<3$	$3\le t_d<9$	$9\le t_d<24$
A	t_d+9.5	-4.5	t_d-15.5	—	—	—
B	—	—	—	t_d+9.5	-4.5	t_d-13.5

ability to coat the BOF slag aggregates.

Temperature Prediction Models

Two flexible pavement temperature prediction models were used to estimate the temperatures at certain depths of the asphalt specimens with various BOF slag content. The two models are the Michigan model, developed by Park *et al*. [12] and the BELLS model. The Michigan model has the following form:

$$Tz = Tsurf + \left(-0.3451z^2 - 0.0432z^2 + 0.00196z^3\right) * \sin\left(-6.3252t + 5.0967\right) \quad (1)$$

where,

T_z = temperature at depth *Z* of pavement (°C)

T_{surf} = surface temperature of pavement (°C)

Z = depth of pavement (mm)

t = time at temperature estimation (min.)

In the BELLS model, the effect of shadow on the temperature was taken into consideration, and was controlled to below 1 min. The model also considers the highest and the lowest temperature during the day of the test. The model is listed as follows:

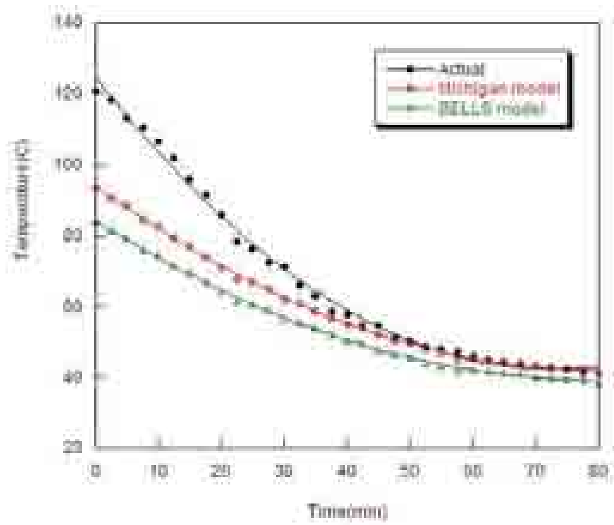
$$T_d = 0.95 + 0.893T_s + \left(\log d - 1.25\right) * \left[1.83\sin\left(2\pi A/18\right) - 0.448T_s + 0.621T_{avg}\right] + 0.042T_s \sin\left(2\pi B/18\right) \quad (2)$$

T_d = temperature at depth d of pavement (°C)

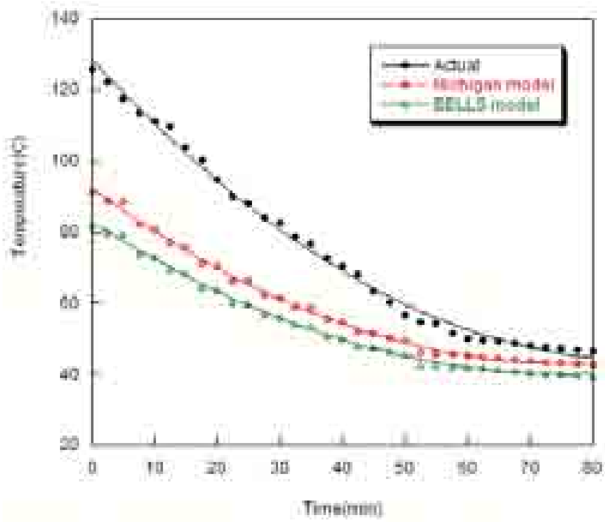
T_s = surface temperature of pavement (°C)

T_{avg} = average of the highest and lowest temperature in test day (°C)

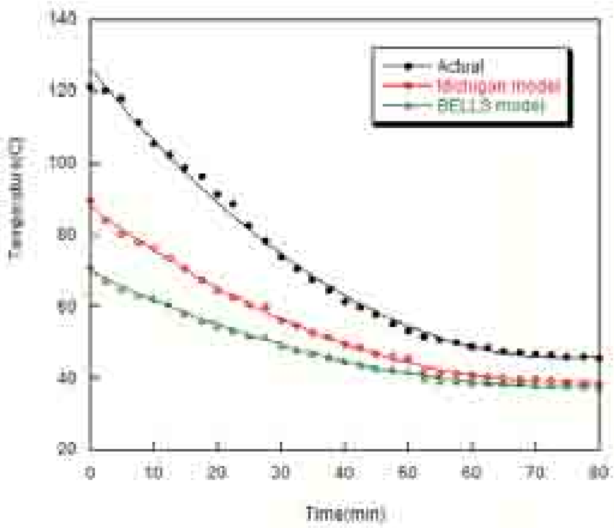
d = depth d of pavement (mm)



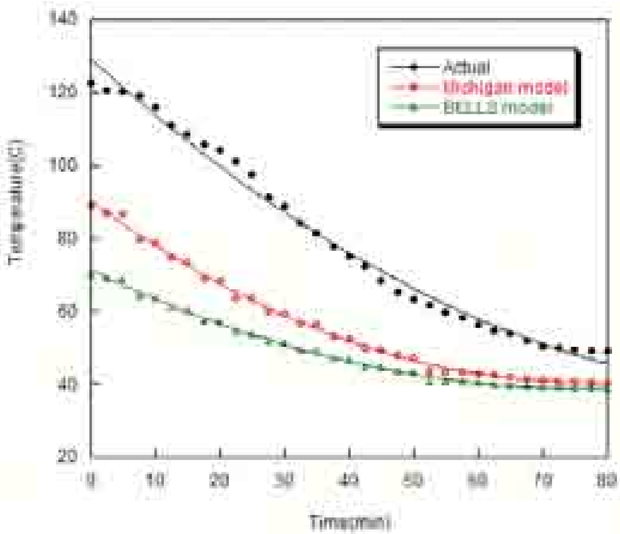
(a) BOF 0% at 2cm



(b) BOF 60% at 2cm



(c) BOF 0% at 6cm



(d) BOF 60% at 6cm

Fig. 11. Comparisons of Predicted and Measured Temperatures.

t_d = test time (24hr)
A, B = equation parameter, as listed in Table 4.

The Michigan model and the BELLS model were sue in estimating the temperatures through the cooling process for asphalt samples with 0% and 60% BOF slag, and at depths of 2 cm and 6 cm, as shown in Fig. 11. As can be seen from the figure, both models tend to underestimate the measured temperatures, especially in the initial stage while the asphalt temperature is high. At 2 mm depth, predicted values from the two models are close to the measured after about 40 minutes for asphalt samples with no BOF slag; however, for samples with 60% BOF slag, the discrepancies between the predicted and measured values are larger. From the figures, is also noted that the Michigan model seems to better estimate the measured values as compared to the values predicted by the BELLS model.

Conclusions

The effects of the use of BOF slag as coarse aggregate replacement on the temperature behavior of hot mix asphalt mixtures were evaluated. From the study, the following conclusions can be drawn:

1. The use of BOF slag as aggregate can reduce the rate of temperature drop. The mixtures reached a thermal equilibrium at about 70°C. As the BOF slag content increases, the time required for the mixtures to reach a temperature increases. Therefore, longer time for transportation can be allowed.
2. Bothe the Initial temperature and the Cessation Temperature decrease as the BOF slag content in the mixtures increases. This indicates that asphalt mixtures with BOF slag can be compacted at lower temperatures as compared with those without BOF slag.
3. Time required for opening to traffic increased slightly for mixtures containing BOF slag, roughly about 5 to 10 minutes with 20% to 100% BOF slag contents.
4. In the Initial Temperature Interval, the cooling rate decreases as the BOF slag content increases. The rate was 1.29 °C/min. for asphalt with no BOF slag to 1.06 °C/min. for mixtures with 100% BOF slag as coarse aggregates. The BOF slag content had little on the Cessation and Opening Temperatures.
5. For all asphalt samples, with or without BOF slag, the samples did not gain sufficient strength until the mixture temperature reached about 60°C. Asphalt samples containing 60% of BOF slag did show slightly higher indirect tensile strength. No significant differences were observed for all other samples.
6. Neither the Michigan temperature prediction model nor the BELLS model was able predict the internal temperature of the asphalt accurately.

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