Investigation on the combined recycling of reclaimed asphalt pavement and steel slag in asphalt mixture at low temperature

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The use of recycled materials in asphalt mixture for road pavement application is common practice due to economic and environmental benefits. Commonly, only a single waste material or homogenous materials are recycled, such as reclaimed asphalt pavement (RAP) and roofing bituminous shingles. RAP is the most commonly recycled material in asphalt pavement (Moon *et al.*, 2016); this consists of old pavement surface material (aggregate and asphalt binder) which is reduced in small particles during the milling process. When combined with new aggregate and binder it provides a valuable contribution to the preparation of new mixtures.

Other materials, such as reclaimed Portland cement concrete, fly ash, waste tire rubber, waste glass, among others, were investigated in the past, either as surrogate aggregate or binder modifier. Among these alternative materials, steel slag has received considerable attention since, as demonstrated in recent studies (Poulikakos *et al.*, 2017; Groenniger *et al.*, 2017), it can potentially replace the entire aggregate skeleton of the mixture. Nevertheless, very limited research effort was devoted to the investigation of the combined use of RAP and steel slag in asphalt mixture (Brand and Roesler, 2014), especially at low temperature, where the aged RAP material may substantially affect mixture and pavement performance.

In this research, the effect of the combined use of RAP and steel slag on the low temperature mechanical response of asphalt mixture is experimentally investigated based on creep and fracture test. For this purpose, a set of 8 asphalt mixtures prepared with two different asphalt binders, having different performance grade (PG) (AASHTO M320, 2016) and different contents of RAP and steel slags were prepared. Same gradation curve and nominal maximum aggregate size, NMAS=12.5mm, were selected for the mix design as shown in Table 1.

Table 1. Asphalt mixtures mix design.

Mix ID	Asphalt Binder	RAP (%)	Steel Slag (%)	Air Voids (%)
A	PG 64-28	0	0	4
B	PG 64-28	25	0	4
C	PG 64-28	25	75	4
D	PG 64-28	0	100	4
E	PG 64-34	0	0	4
F	PG 64-34	25	0	4
G	PG 64-34	25	75	4
H	PG 64-34	0	100	4

Low temperature creep tests were performed on small asphalt mixture beams in three-point bending configuration with the Bending Beam Rheometer (BBR) (Marasteanu *et al*. 2009). Stiffness, $S(t)$, relaxation properties, as well as thermal stress, $\sigma(T)$, and critical cracking temperature, T_{cr}, were computed based on Laplace transformation. Together with creep tests, low temperature fracture tests were performed on notched specimens according to the Semi-Circular Bend (SCB) testing procedure (Cannone Falchetto *et al.*, 2016) (Figure 1a). Peak load, P_N, fracture energy, G_F, and Mode I fracture toughness, K_I, were then calculated.

The experimental results obtained from BBR creep tests suggests an increasing stiffness and partially reduced relaxation properties associated with slag and RAP content, with an intermediate behavior when RAP and steel slag are combined (RAP-slag mixture). Higher thermal stress is observed when the recycled material is used; this only partially affects the critical cracking temperature.

A substantial increase in the peak load is found from the SCB tests. Highest load is observed when 100% slags are used in the mix design. A slightly lower peak load (Table 2) is measured when RAP is combined with slags, mitigating the benefit of the recycled aggregates. An overall increase in fracture energy and fracture toughness is also obtained when slangs and RAP are both included in the mix design (Table 2). This suggests that the combined use of RAP and steel slag is overall beneficial to the fracture properties of the recycled mixture, as the formation of a crack requires more energy than when using only virgin material.

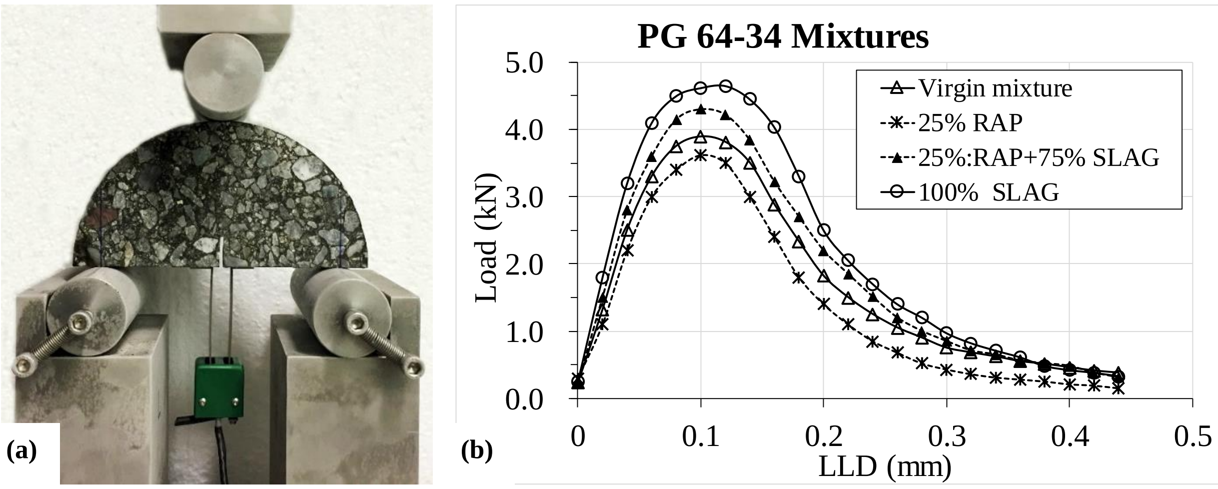

Figure 1. (a) SCB testing setup and (b) Load vs LLD curves for PG 64-34 mixtures.

Table 1. Table of asphalt mixtures mix design.

Mix ID	Asphalt Binder	RAP (%)	Steel Slag (%)	Air Voids (%)	Peak Load(kN)	G_F (kN/m)	σ_n (kPa)	K_I (MPa*m$^{0.5}$)
A	PG 64-28	0	0	4	3.74	0.483	1,251	1.092
B	PG 64-28	25	0	4	3.50	0.390	926	1.011
C	PG 64-28	25	75	4	4.13	0.538	1,094	1.195
D	PG 64-28	0	100	4	4.41	0.606	1,180	1.312
E	PG 64-34	0	0	4	3.89	0.507	1,037	1.157
F	PG 64-34	25	0	4	3.62	0.411	965	1.077
G	PG 64-34	25	75	4	4.30	0.567	1,146	1.279
H	PG 64-34	0	100	4	4.65	0.642	1,240	1.383

The present experimental investigation provides evidence that the combined use of RAP and slag represents a valuable alternative to the recycling of single materials in the asphalt mixture. This is demonstrated by the better mechanical performance of the RAP-slag mixtures in comparison with those prepared with virgin material. This is true both for creep and fracture response. Such a result supports the idea of combined material recycling in asphalt pavement, with increased environmental benefit, as more waste materials can be used, while reducing pavement construction and material costs.

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