QUICK REFERENCE GUIDE 4 - 2015

Electric Arc Furnace Slag

australasian (iron & steel) slag association

INTRODUCTION

Electric Arc Furnace Slag (EAFS) is a co-product of the steel making process. The production of EAFS involves steel scrap and fluxes which are added to a refractory lined cup-shaped vessel. This vessel has a lid through which carbon electrodes are passed. An arc is induced between the scrap and electrodes and the resultant heat generated melts scrap and fluxes producing molten steel and slag[1].

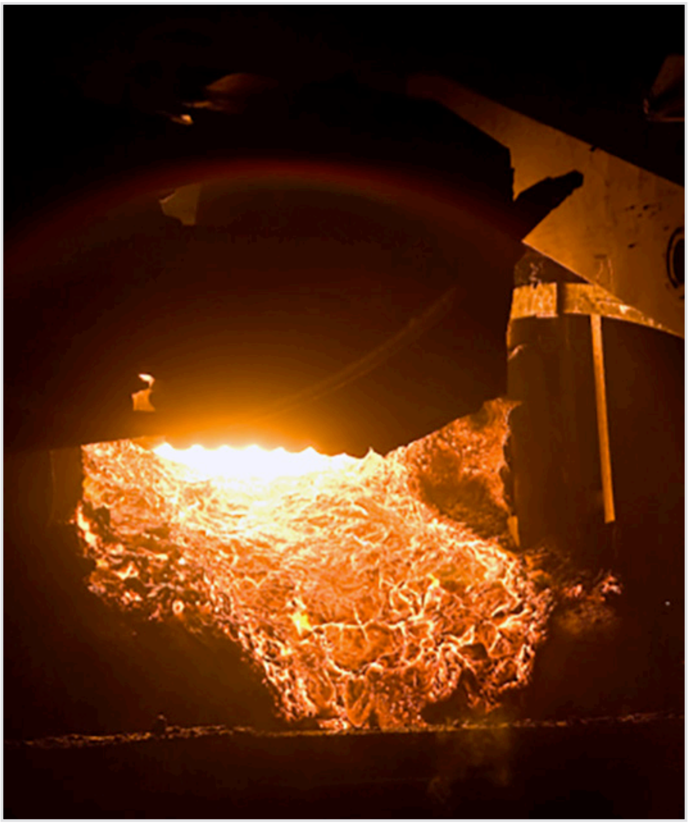

Figure 1 - Electric Arc Furnace

Typical physical properties of EAFS aggregates, after processing to remove metallic's are shown in Table 1.

Through its research activities between relevant stakeholders, the Australasian (iron & steel) Slag Association continues to increase the recognition and understanding of the beneficial use of iron and steel slags amongst industry members, government and the community though projects such as the Quick Reference Guide (QRG) Update.

This QRG updates the Guide to the use of Iron and Steel slag in roads, focusing on the specific aspects related to the use of Electric Arc Furnace Slag (EAFS) in terms of its physical and chemical characteristics, applications and case studies.

TYPICAL PHYSICAL PROPERTIES

Table 1 - Typical Physical Properties of EAFS[2].

Typical Physical Properties - Aggregate	Electric Arc Furnace Slag
Bulk Density (t/m³)(loose)	1.60 - 2.10
Particle Density (t/m³)	3.30 - 3.45
Dry Strength (kN)	220 - 270
Wet Strength (kN)	200 - 250
Wet/Dry Variation (%)	5 - 15
Water Absorption (%)	1 - 2 (coarse aggregate) 2 - 4 (fine aggregate)
LA Abrasion (%)	15 - 20
Polished Aggregate Friction Value (PAFV)	58 - 62
Sodium Sulfate Soundness (%)	< 4
Flakiness Index (%)	< 5
Free Lime (%)	< 3
Physical Property- 20 mm Road base	
Maximum Dry Density (kg/m³)[1]	2,300 - 2,600
Optimum Moisture Content (%)[2]	8 - 12

Notes:
[1] MDD based on 100% standard compaction.
[2] OMC OMC depends on the particle size distribution of the mix.

EAFS is dark grey in colour and characteristically harder than natural aggregates. It has a density about 20 - 25% greater than basalt. It crushes to a cubical shape.

EAFS may contain small amounts of potentially expansive products such as burnt lime and dolomite. Sufficient moisture and time must be provided to enable hydration of these materials, commonly known as weathering. Weathering is typically achieved by periodic watering, monitoring and internal stockpile management procedures before releasing for use.

TYPICAL APPLICATIONS

EAFS is similar to Steel Furnace Slag (SFS) with self-cementing properties for heavy duty pavement applications. Unconfined compressive strength (UCS) > 5 MPa has been achieved at 28 days bench cured at 23°C. As a tough, durable material, EAFS has excellent skid resistance comparable to rhyolite. Resistance to rutting also makes EAFS particularly applicable for heavily trafficked corners and stopping zones.

Typical applications for EAFS include:
- Sealing aggregate (skid resistant)
- Asphalt aggregate
- Road Base, Sub-base (bound and unbound)
- Construction fill

Typical applications for the use of EAFS are referenced in various State Road Authority specifications as shown in Table 2.

Table 2 - Specifications for the use of EAFS.

EAFS Type	RMS[3]	VicRoads[4]
Unbound	R71	304
Bound	R73	815
Select Fill	R44	812
Aggregate	3152	404 - 407

Asphalt
The types of asphalt commonly used that could incorporate EAF slag aggregates[5] are:
- Dense Graded Asphalt (DGA) (or Asphaltic Concrete
- Open Graded Asphalt (OGA)
- Stone Mastic Asphalt (SMA)
- Fine Gap Graded Asphalt (FGGA)
- Ultra-Thin Asphalt (UTA) Surfacings including Thin Open Graded Asphalt

EAF slag aggregates can be incorporated into any of the above mix types as an alternative to natural aggregates or to take advantage of the unique properties.

The pH value of the aggregate product leads to a natural affinity to bitumen and binders, leading to reduced stripping and lowers the requirement for lime additions during the production process.

One of the main benefits of EAF slag it's skid resistance performance combined with its ability to maintain properties for significantly longer than most natural aggregates. In place SMA mix designs have shown the SFC of slags has maintained a 15% increase over natural aggregates over time.

This leads to the consideration for the use of EAF slag sealing aggregates in applications where increased and maintained skid resistance can help lead to improved safety and reduced accidents.

Case Study 1: Emerald-Monbulk Road, Victoria

Figure 2 - Emerald-Monbulk Road, Victoria using EAFS

Slag asphalt was laid in the northbound direction with granite asphalt in the southbound direction.

Using a VicRoads SCRIM machine, assessment of skid resistance properties between EAFS and natural materials was conducted. Results of the testing showed that the average skid resistance was 6.5% higher for the EAFS asphalt compared to granite.

A 2013 independent University report then used these results as part of a study into the beneficial impact of skid resistance on pedestrian injuries over the life of the road. This report recognised that EAFS asphalt exhibits superior skid resistance properties which last for long periods as the new frictional surfaces are regenerated on the surface of the material[6].

EAFS asphalt aggregates have subsequently been specified and used at numerous sites throughout Melbourne.

SUB-BASE & BASE COURSE

EAFS has been successfully used as a sub-base by:

(a) Using a minus 40mm crusher run material;
(b) Blending minus 20 mm or minus 40 mm material; or
(c) Blending with granulated blast furnace slag.

EAFS has been used in two main applications as a base course.

The material has been blended at a rate of about 40% with existing base materials to rehabilitate existing pavements where the EAFS increased the wet/dry strength value, decreased the Plasticity Index and modified the pavement materials such that it now conforms to a DGB20 specification in accordance with RMS Specification 3051.

EAFS has also been blended with granulated blast furnace slag (GBFS) to form a bound base material. These blended materials offer slower setting due to the lower free lime content, but UCS values over 4 MPa can be achieved, ensuring the material meets the heavily bound criteria.

CONSTRUCTION CONSIDERATIONS

Construction joints occur where bound material is placed against previously placed bound material which is outside the bound material's working time. Where this occurs, a clean, compacted, vertical perpendicular surface should be cut to the full depth of the pavement layer thickness for both transverse and longitudinal construction joints. This will reduce the risk of plating effects on the pavement. All spoil material should be discarded and not incorporated back into the works.

As with all rigid pavements, the correct management and placement techniques should be considered such as:

- Correct location of joints limiting the overall pavement widths;
- Ensuring the joints are not in wheel paths; and
- Ensuring joints in sub-base layers are offset to joints in the base layer.

Suppliers product data and handling recommendation should be consulted for guidance where appropriate.

Case Study 2: Wyong Rd Tuggerah 2014

Heavily bound pavement material produced using a blend of EAFS with other resource recovered materials was chosen by the New South Wales Roads and Maritime Services (RMS) for the purpose of pavement rehabilitation in sections of Wyong Road at Tuggerah.

Figure 3 - Wyong Rd Tuggerah

The above figure 3 shows a section of existing road boxed out and ready for placement of EAFS based heavily bound pavement material.

The works required a pavement material to be placed, compacted (reaching required specified relative densities), then sealed and opened to traffic all within a 10 hour construction window.

The EAFS based heavily bound pavement material was placed in 1 layer (up to 400mm deep) and sealed once compaction targets were achieved. The road was opened for traffic within hours of the final seal being placed. Performance of the material was critical for RMS.

Using standard placement methodologies the material was placed over a number of different subgrade types from weathered sandstone to poor quality clay based materials.

Figure 4 - Wyong Rd Tuggerah

Figure 4 shows another section ready for placement of the EAFS based heavily bound pavement material.

The material was also placed during light rain with no effect to the final product quality or compaction process.

Due to the high density results, RMS were able to reduce the time required for compaction (compared to their standard practices) whilst achieving the relative density on a single thick layer.

This enabled RMS to expedite placement of the material and progress construction faster than expected. A 70mm asphalt wearing course was placed over the pavement layer, opening within hours of completion.

ENVIRONMENTAL CONSIDERATIONS

Several comprehensive studies of EAFS have shown this material and laboratory generated leachates contains trace amounts of metal well below trigger levels for environmental investigation

NSW Environment Protection Authority (EPA), have issued resource recovery orders and resource recovery exemptions for generators, processors and consumers of EAFS within a range of applications[7].

The primary environmental risk when utilising EAFS in road making applications is the potential for alkaline leachate to enter local waterways. This risk is minimal when EAFS is incorporated into well-designed and constructed roads with adequate drainage. Alkalinity decreases over time as the material gains strength.

Water sheeting off a road or hardstand area is not in contact with EAFS for a long enough period to produce high pH run-off. Hours to days of direct stagnant contact with EAFS are required for the pH of the water to reach environmentally significant levels.

CONCLUSION

EAFS being a co-product of the steel making process is produced using controlled inputs. These controlled inputs ensure a homogeneous output where the physical and elemental properties can be relied on for consistency. This can provide benefits over naturally occurring aggregates and pavement materials where variability within natural deposits related to geological weathering and alterations can occur.

Along with the above, environmental benefits are significant for a reduced carbon footprint along with conservation of natural resources.

REFERENCES

[1] http://www.asa-inc.org.au/products/electric-arc-furnace-slag [accessed 2015]

[2] ASA (2002). A Guide to the Use of Slag in Roads. Revision 2. Wollongong, Australasian (iron & steel) Slag Association Inc. with amendments

[3] http://www.rms.nsw.gov.au/business-industry/partners-suppliers/specifications/index.html [accessed 2015]

[4] https://www.vicroads.vic.gov.au/business-and-industry/tenders-and-suppliers/contractors-and-consultants/standard-documents [accessed 2015]

[5] ASA (2001). A Guide to the Use of Steel Furnace Slag in Asphalt and Thin Bituminous Surfacings. Wollongong, Australasian (iron & steel) Slag Association Inc.

[6] Jones, N 2010, 'Paper 22 The regenerative frictional properties of slag aggregate', Harsco Metals Group Limited

[7] http://www.epa.nsw.gov.au/wasteregulation/orders-exemptions.htm [accessed 2015]

AUSTRALASIAN (IRON & STEEL) SLAG ASSOCIATION

Suite 2, Level 1, 336 Keira Street,
Wollongong NSW 2500 Australia

PO Box 1194
Wollongong NSW 2500 Australia

Telephone: +61 2 4258 0160
Fax: +61 2 4258 0169
Email: info@asa-inc.org.au