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AUSTRALASIAN SLAG ASSOCIATION INC 1990

# A Guide to the Use of Steel Furnace Slag in Asphalt and Thin Bituminous Surfacings

# AUSTRALASIAN SLAG ASSOCIATION


Member Companies Location

**Slag Production and Member Locations in Australasia and South East Asia**

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A Guide to the Use of Steel Furnace Slag in Asphalt and Thin Bituminous Surfacings.

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# FOREWORD

This "Guide to the Use of Steel Furnace Slag in Asphalt and Thin Bituminous Surfacings" is the third in a series of publications to promote understanding and the appropriate usage of slag based products. The other publications were "A Guide to the Use of Slag in Roads" published in June 1993 and "A Guide to the Use of Iron Blast Furnace Slag in Cement and Concrete" published in April 1997.

The Australasian Slag Association is grateful for the co-operation and valuable input received from the Roads and Traffic Authority NSW, VicRoads, and the Australian Asphalt Pavement Association in the production and the publication of this Guide.

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<u>DISCLAIMER</u>

The Australasian Slag Association is a non-profit organisation, which has been formed to provide a forum for exchange of information between its members and others. Since the information contained in its publications is intended for general guidance only, and in no way replaces the services of professional consultants on particular projects, no legal liability or otherwise can be accepted by the Association for the information contained in this publication.

# 1. INTRODUCTION

## 1.1 Purpose of the Guide.

This Guide, which is supplementary to the Association's *Guide to the Use of Slag in Roads*, reviews in detail the use of steel furnace slag in asphalt and thin bituminous surfacings. The Guide shows that, with technical evaluation supported by field experience that steel furnace slag has in many applications, properties suitable to replace, supplement and improve other materials. The use of steel furnace slags in these ways also has environmental benefits in allowing the conservation of depleting natural resources.

The purpose of this Guide is to provide information to designers, specifiers and providers of bituminous road surfacings on the properties of steel furnace slag aggregates so that they may be considered on an informed basis when comparisons are being made with other aggregates.

The Guide forms part of an continuous improvement process which aims to optimise the opportunities for the use of steel furnace slag aggregates.

As there are many types of slag, it should be emphasised that this booklet refers particularly to basic oxygen steelmaking slag and/or electric arc furnace slag which are steel furnace slags.

## 1.2 Background.

Steel furnace slag is formed during the manufacture of steel. It has a complex chemical structure comprised of oxides and silicates. Local processors and suppliers have utilised expertise from overseas and Australasian experience to develop sound management procedures for the handling of steel furnace slag to optimise its quality. The experience in processing and developments in utilisation have resulted in a high level of performance of asphalt containing steel furnace slag.

Steel furnace slag has many properties, which make it well suited for use in bituminous surfacings. It is a hard, dense, durable and well-shaped aggregate which has an affinity for bitumen and acts as a strong matrix in asphalt. The skid resistance properties of steel furnace slag make it a very useful aggregate for asphalt surfacings including open grade asphalt, dense grade asphalt, fine gap graded asphalt and stone mastic asphalt.

In thin bituminous surfacings, the cubical shape and skid resistant properties enhance the performance of surfacings such as slurry seals, sprayed seals and emulsion seals.

Over the last decade the use of steel furnace slag in asphalt has become widely accepted, particularly in the Wollongong Region of New South Wales. Its acceptance in the Sydney Region is increasing and there has been some used in the Newcastle Region of New South Wales for Asphalt. This follows over 20 years experience overseas including the US, UK and Europe where steel furnace slag has been widely used and is accepted as a premium asphalt aggregate (1).

In New Zealand melter slags have been successfully utilised in cold emulsion mixes and slurry seals. The coldmix has performed well under heavy-duty loadings and has been developed with recycled rubber buffings for use in golf course walkways.

Steel furnace slags have been used in open graded asphalt and sprayed sealing applications on the state highway network for Transit New Zealand.

In other overseas countries blast furnace slag aggregates, which are a by-product from the making of iron, are also used in asphalt. At this time only steel furnace slag aggregates are used in bituminous surfacings in Australia.

Steel furnace slag is a valuable industrial by-product. Its increased use in bituminous surfacings will result in improved performance for the road user and owner and a decrease in the demand for our limited natural resources.

The locations of steel production centres within Australasia are shown inside the front cover.

# 2. PRODUCTION AND PROCESSING STEEL FURNACE SLAGS

## 2.1 Furnace Processes

Steel furnace slag is formed during the manufacture of steel. It has a complex chemical structure of oxides and silicates.

There are two main methods of manufacturing steel in Australasia:

- Basic Oxygen Steelmaking (BOS)
- Electric Arc Furnace Steelmaking (EAF).

In the Basic Oxygen Steelmaking process, molten iron from the blast furnace ironmaking process is placed in a refractory lined vessel with steel scrap and fluxes (lime and dolomite). Large volumes of oxygen are blown through a water-cooled injection lance into the molten material to melt the scrap and flux and refine the metal to produce the required quality steel. After 30 to 40 minutes the resultant molten products are 200 to 250 tonnes of steel and 25 to 30 tonnes of slag.

**Decanting Slag**

In the Electric Arc Furnace Steelmaking process, iron and steel scrap and fluxes (lime and dolomite) are again placed in a refractory lined vessel. Carbon electrodes are lowered into the vessel, and an electric arc is induced. This arc is maintained to melt and refine the scrap steel, lime and dolomite. After 40 to 50 minutes the resultant molten products are 70 to 90 tonnes of steel and 8 to 10 tonnes of slag.

The slag in both EAF & BOS processes floats on the surface of the steel and is removed from the vessel after decanting of the molten steel. Some steel remains within the slag produced. The slag produced by both processes is similarly treated by tipping into pits for cooling.

**Tipping of Molten Steel Furnace Slag**

## 2.2 Cooling and Transporting

Once in the pits, the material is allowed to cool until solidification occurs. Cooling is often accelerated with the addition of controlled amounts of water. The addition of water also aids in cracking the slag into more manageable sizes for loaders to be able to dig and remove the slag from the pits.

The slag is loaded onto vehicles and moved to an area for further watering prior to processing.

## 2.3 Metallics Separation

Unprocessed steel furnace slag contains metallics, which are separated from the slag during processing in purpose-built metal recovery plants. These plants operate on a basis of magnetic separation and use various types of magnets throughout the process to remove recoverable metaltics.

The metal recovered is recycled back into the steel making process.

After the initial removal of metallics, steel furnace slag is then ready for aggregate production.

## 2.4 Processing - Crushing and Screening

Steel furnace slag is processed in a manner similar to the production of aggregates at any quarry.

Slag is fed to crushers and after reducing to the required maximum size is screened into the required grades. For asphalt and thin bituminous surfacings, aggregate sizes are usually 20 mm, 14 mm, 10 mm, 7 mm and slag fines. After conditioning and weathering, various aggregates may be combined in design proportions to produce a blended aggregate as specified by the customer.

It is possible to recover further metallics after crushing. This occurs using the same methods as described in Section 2.3. Recovery of metallics after crushing is the only significant difference when comparing operations of a slag processor to those of a quarry.

**Steel Furnace Slag Processing Plant, Port Kembla NSW.**

## 2.5 Stockpiling - Conditioning and Weathering

Steel furnace slags in Australia may contain small amounts of expansive product such as burnt lime and dolomite. Also, the slag particles themselves can be expansive until they are fully hydrated. Sufficient moisture and time must be provided to enable these materials to react before the aggregate can be used.

This may be achieved by either:-

- Stockpiling the slag aggregates for sufficient time to allow moisture from the atmosphere (i.e. rain and humidity) to react with the slag particles, lime and dolomite, or
- Regularly watering the slag aggregates, thereby accelerating the conditioning process.

A test has been developed by the CSIRO (2) to ensure sufficient weathering has taken place. This is discussed in Section 3.2.12.

## 2.6 Quality Assurance Procedures

In Australia, and particularly New South Wales, it is normal industry practice to supply aggregates and roadbase under a Quality Assurance regime. Producers of BOS slag aggregates have in place registered Quality Assurance schemes.

The Quality Assurance schemes, which have been adapted and improved from UK and USA experience, provide detailed procedures covering all aspects of slag production and processing. Testing is performed regularly with aggregates being tested prior to dispatch to provide the customer with confidence in slag materials.

# 3. PROPERTIES OF BASIC OXYGEN STEELMAKING AND ELECTRIC ARC FURNACE SLAGS

## 3.1 Chemistry

Typical Chemistry of both BOS and EAF slags, after appropriate conditioning and weathering as discussed in Section 2.5, are shown in Table 3.1.

**Table 3.1 - Chemistry of Steel Furnace Slags**

| Constituents as Oxides | BOS Slag (%) | EAF Slag (%) |
|---|---|---|
| Calcium Oxide (CaO)<br>% Free Lime | 40<br>0 – 2 | 35<br>0 - 1 |
| Silicon Oxide ($SiO_2$) | 12 | 14 |
| Iron Oxide ($Fe_2O_3$) | 20 | 29 |
| Magnesium Oxide (MgO) | 9 | 7.7 |
| Manganese Oxide (MnO) | 5 | 5.7 |
| Aluminium Oxide ($Al_2O_3$) | 3 | 5.5 |
| Titanium Oxide ($TiO_2$) | 1 | 0.5 |
| Potassium Oxide ($K_2O$) | 0.02 | 0.1 |
| Chromium Oxide ($Cr_2O_3$) | 0.1 | 1 |
| Vanadium Oxide ($V_2O_5$) | 1.4 | 0.3 |
| Sulphur (S) | 0.07 | 0.1 |

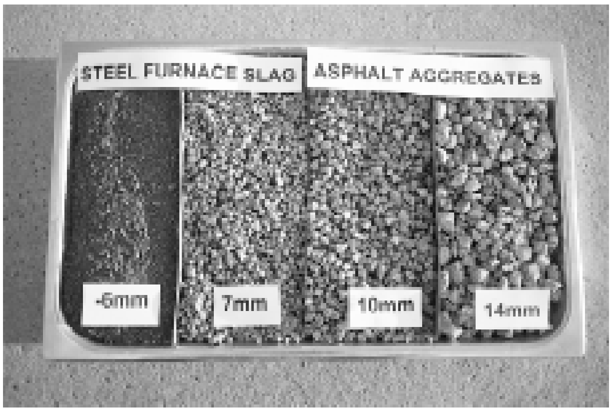
## 3.2 Physical Properties

The physical properties of steel furnace slag aggregate are described below and summarised in Table 3.2.

### 3.2.1 Grading

Steel furnace slag aggregates are screened into individual sizes that conform to standard aggregate grading specifications. From the individual sizes it is possible to blend aggregates to gradings as required for use in asphalt. The individual sizes are also suitable for use in thin bituminous surfacings.

The only minor difference in grading between steel furnace slag and quarry products is that steel furnace slag aggregate generally will have a slightly lower percentage of material passing the 75 micron sieve. This is often an advantage in asphalt as it allows more flexibility in the type and quantity of filler added.




**Graded Aggregates**

### 3.2.2 Average Least Dimension

The Average Least Dimension (ALD) of steel furnace slag aggregates is generally higher than for naturally occurring aggregates of the same nominal size. This reflects the cubical shape of the aggregates.

It has also been shown that the higher ALD also occurs on the lower size fractions eg 4.75 mm to 6.7 mm. This property has been linked with improved performance of asphalt in terms of deformation resistance. For the fraction 6.7 mm to 9.5 mm a typical ALD is 6.7 mm and for 4.75 to 6.7 mm the range is 4.5 mm to 5.2 mm. In both cases these results exceed the value for what is considered to be well shaped aggregate for use in asphalt.

### 3.2.3 Particle Shape

BOS slags have a predominantly cubical particle shape. This is verified by the low results for Misshapen Particles of less than 10% for 2:1 and less than 2% for 3:1 when tested by proportional calipers in accordance with AS 1141.14 (3).

The cubical shape of steel furnace slag aggregates is an advantage for aggregate interlock and hence improving the deformation resistance of asphalt containing BOS Slag.

In sprayed seal applications, the particle shape of steel furnace slag aggregates is well within specification limits.

### 3.2.4 Fractured Faces

All steel furnace slag has 100% fractured faces when tested in accordance with Roads and Traffic Authority (NSW) Test Method RTA T239 (4). Fractured faces also improve the aggregate interlock and hence matrix stability.

### 3.2.5 Density

The particle densities of steel furnace slags are as follows:-

- EAF slag
  - in the order of 3,300 kg/m$^3$, dry
  - 3,400 kg/m$^3$, Saturated Surface Dry (SSD).
- BOS slag
  - 3,300 kg/m$^3$ to 3,400 kg/m$^3$, dry
  - 3,350 kg/m$^3$ to 3,450 kg/m$^3$, SSD.

While these densities are higher than those of conventional aggregates, this does not translate directly to a proportional increase in the cost of placed asphalt. While there may be increases in haulage costs and a reduction in m$^3$/tonne of asphalt laid, costs of binder, mixing and placing are the same as when using conventional aggregates.

### 3.2.6 Particle Strength

Steel furnace slags have high particle strength, which is an advantage for asphalt.

The high particle strength combines well with the cubicle shape to give a matrix which is able to transfer very high loads, and is very resistant to deformation in asphalt. Testing for particle strength is performed in accordance with AS 1141.22 (5).

The high particle strength combined with the cubical shape makes steel furnace slag aggregates suited to applications such as stone mastic asphalt and open grade wearing surfaces. In both these types of asphalt there is considerable direct contact between aggregate particles.

In sprayed seals, strong particles significantly reduce the risk of the seal flushing due to particle breakdown, which reduces the effective average least dimension of the aggregate particles.

BOS slag has a dry strength of about 250 kN. The dry strength can range up to 350 kN for the smaller particle fractions such as 7 mm and 10 mm. The wet strength is in the range of 230 kN to 300 kN.

For BOS slag the wet/dry strength variation is in the range 5 to 20% and for EAF slag the wet/dry strength variation is in the range 5 to 15%. These low values indicate materials where particle strength is not significantly affected by moisture.

### 3.2.7 Abrasion Resistance

Abrasion resistance is tested using the Los Angeles Abrasion test in accordance with AS

1141.23 (6). The Los Angeles Value (B) for BOS slag is in the range of 12 to 18. For EAF slag the Los Angeles Value is of the order of 16.

These results indicate that steel furnace slags have a high abrasion resistance, which again is an advantage for asphalt. This is particularly so when the asphalt is in high stress areas such as heavily trafficked domestic and industrial locations and intersections.

### 3.2.8 Water Absorption

The water absorption of steel furnace slag is similar to naturally occurring aggregates. The water absorption for both BOS and EAF slag is 1% to 2% for coarse aggregates (7 mm and larger). For fine aggregates, the water absorption is 2% to 4%. These results are consistent with naturally occurring aggregates and indicate that additional bitumen is not required for absorption.

The surface area of steel furnance slag aggregates is slightly greater than naturally occuring aggregates due to cubical particle shape and the vesicular nature of the particle surface. Additional binder in the order of 0.5% by mass is required to coat the increased surface area.

### 3.2.9 Skid Resistance

Steel furnace slag has a Polishing Aggregate Friction Value PAFV (9) (which is similar to the Polished Stone Value Test) greater than most naturally occurring aggregates. The range of values for BOS slag is usually 52 to 58 and for EAF slag 58 to 63. The naturally occurring aggregates with PAFVs greater than these values are some rhyolites and scorias which tend to have lower wet strengths and abrasion resistance than steel furnace slag.

Steel furnace slag aggregates have been successfully used in high accident areas such as intersections and low radius curves with reduced accident rates resulting (12). The friction measurements determined by the Sideways Force Coefficient Routine Investigation Machine (SCRIM) have also been shown to be high.

Typical SCRIM results for steel furnace slag aggregates from case studies are presented in Section 7. Table 3.3 provides typical investigatory skid resistance levels for SCRIM values. (13)

**Table 3.2 - Table of Important Properties of BOS and EAF Slags**

| Property | EAF Slag | BOS Slag |
|---|---|---|
| Particle Density (AS1141.5 & 6) (7) (8) | 3,300 kg/m$^3$ dry<br>3,400 kg/m$^3$ SSD | 3,300 to 3,400 kg/m$^3$ dry<br>3,350 to 3,450 kg/m$^3$ SSD |
| Particle Shape (AS1141.14) (3) | < 10% 2:1<br>< 2% 3:1 | < 10% 2:1<br>< 2% 3:1 |
| Dry Strength (AS1141.22) (5) | 275 to 350 kN | 250 to 350 kN |
| Wet Strength (AS1141.22) (5) | 240 to 300 kN | 230 to 300 kN |
| Wet / Dry Strength Variation (AS1141.22) (5) | 5 - 15% | 5 - 20% |
| Water Absorption (AS1141.5 & 6) (7) (8) | 1% to 2% coarse aggregate<br>2% to 4% fine aggregate | 1% to 2% coarse aggregate<br>2% to 4% fine aggregate |
| Fractured Faces (RTA T239)(4) | 100% | 100% |
| LA Abrasion (AS1141.23)(6) | 16(B) | 12 to 18 (B) |
| Polishing Aggregate Friction Value (AS1141.41/42)(9) (10) | 58 to 63 | 52 to 58 |
| Sodium Sulphate Soundness (AS1141.24) (11) | < 4% | < 4% |

## Table 3.3 - Examples of Investigatory Skid Resistance Levels

| Site Category | Site Description | INVESTIGATORY LEVELS OF $SFC_{50}$ at 50km/h or equivalent | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 |
| | | CORRESPONDING RISK RATINGS | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1<br>(See notes) | Traffic light controlled intersections<br>Pedestrian/school crossings<br>Railway level crossings<br>Roundabout approaches | | | INVESTIGATION | | | | |
| 2 | Curves with tight radius ≤ 250m<br>Gradients ≥ 5% and ≥50m long<br>Freeway/highway on/off ramps | | | ADVISED | | | | |
| 3<br>(See notes) | Intersections | | | | | | | |
| 4 | Manoeuvre-free areas of undivided roads | | | | | | | |
| 5 | Manoeuvre-free areas of divided roads | | | | | | | |

| Site Category | Site Description | INVESTIGATORY LEVELS OF $SFC_{20}$ at 20km/h or equivalent | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 |
| | | CORRESPONDING RISK RATING | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6 | Curves with radius ≤ 100m | INVESTIGATION | | | | | | |
| 7 | Roundabouts | ADVISED | | | | | | |

KEY TO THRESHOLDS AT OR BELOW WHICH INVESTIGATION IS ADVISED

(grey) all primary roads, and for secondary roads with more than 2,500 vehicles per lane per day

(black) roads with less than 2,500 vehicles per lane per day

NOTES for Table 3.2:

- The difference in Sideways Force Coefficient values between wheelpaths (Differential Friction Levels) should be less than 0.10 where the speed limit is over 60km/h; or less than 0.20 where the speed limit is 60km/h; or less than 0.20 where the speed limit is 60 km/h or less.
- Investigatory levels are based on the minimum of the four point rolling average skid resistance for each 100m section length.
- Investigatory Levels for Site Categories 1 and 3 are based on the minimum of the four point rolling average skid resistance for the section from 50m before to 20m past the feature, or for 50m approaching a roundabout.

### 3.2.10 Resistance to Stripping

Steel furnace slags have a strong affinity for bitumen. This has been evidenced by excellent results when steel furnace slag is tested by the Modified Lottman procedure in accordance with RTA test method T640 (14). Samples are tested for modulus in a dry state and then treated by soaking in hot water and sometimes freezing prior to being tested for a wet modulus. The results of these tests when performed on asphalt containing steel surface slag aggregates have exceeded current requirements indicating a high resistance to stripping or moisture damage.

This result would be anticipated in many respects due to the presence of hydrated lime on the surface of steel furnace slag particles. Hydrated lime is a known agent for improving the resistance to stripping and is often added to asphalt as a filler for this purpose.

For use in sprayed sealing applications, BOS slag aggregates tested in accordance with RTA Test Method T230 (15)- Plate Stripping Test, will give conforming results when the appropriate precoating agent is used.

### 3.2.11 Aggregate Soundness

Testing of steel furnace slag aggregates for aggregate soundness using RTA Test Method T266 (16) has shown that there is very little particle loss. Results are less than 4% compared to the current RTA specification requirements of less than 12%.

### 3.2.12 Expansion Characteristics and CSIRO Research

It is possible for small amounts of burnt lime and dolomite to be contained in steel furnace slags. Free lime contents for Australian steel furnace slags are generally significantly lower than for other countries. For EAF slags, the amount of burnt lime is very low, usually less than 0.5%. For BOS slags the percentage is 0 to 2% although usually less than 1%. Burnt lime hydrates very quickly in the presence of adequate moisture and steel furnace slag producers have in place appropriate handling procedures to allow this hydration to occur.

To provide the asphalt producers and their customers with appropriate assurances regarding the expansion characteristics of steel furnace slags, CSIRO have developed a test method for characterising the potential of a steel furnace slag sample to expand (2). The test involves a short immersion period of a sample under water after being saturated under vacuum. This allows moisture to come into contact with any expansive materials very quickly. The grading of the sample is taken before and after testing. This data is used as a measure of the extent of any breakdown of slag particles due to the effect of expansion.

This test method is considered to be a significant improvement on previous test procedures which depended on artificially elevated temperatures such as in an autoclave which is not reflective of field experience. The vacuum method provides an accelerated process at ambient temperatures.

To date it has been shown that there is very little potential for expansion in the smaller particle sizes such as 7 mm and 10 mm, in some cases even for slag which has had very limited weathering. For 14 mm and larger sizes the research has shown that weathering is required in most cases before incorporation of the aggregate in asphalt. Work is continuing to obtain sufficient data to enable further guidelines for acceptance to be established.

It should be noted that asphalt is a very appropriate use for steel furnace slags in respect to potential expansion. This is for a number of reasons.

1 Bitumen coats the steel furnace slag particles. This minimises the opportunity for moisture infiltration into the particles. Also, the high affinity between bitumen and steel furnace slag means that there is minimal opportunity for stripping and hence moisture infiltration into the aggregate particles.

2 Asphalt is a visco-elastic material that is able to tolerate a small amount of expansion.

In Australia, there have been no instances of expansion where appropriately weathered steel furnace slag has been incorporated in asphalt. This is after supply of over 350,000 tonnes up to 1999.

# 4. USE OF STEEL FURNACE SLAGS IN ASPHALT

## 4.1 General

This section describes the types of asphalt mixes in which steel furnace slag aggregates can be used.

## 4.2 Asphalt Mix Types

The types of asphalt commonly used that could incorporate steel furnace slag aggregates are:-

- **Dense Graded Asphalt (DGA) (or Asphaltic Concrete)**

Dense graded asphalt comprises a mixture of continuously graded aggregates, sands, filler and bitumen which is mixed and placed hot. It is the most common type of asphalt.

- **Open Graded Asphalt (OGA)**

Open graded asphalt (or porous asphalt) has a large proportion of coarse aggregate and only a small amount of fine aggregate resulting in a high void content (18 to 25%). It is used as a low noise, low spray wearing surface application

- **Stone Mastic Asphalt (SMA)**

Stone mastic asphalt (SMA) is a durable and rut resistant surfacing mix (sometimes also called Coarse Gap Graded Asphalt (CGGA)). It has a large percentage of coarse aggregate with stone on stone contact, with the remaining air voids partially filled with mastic comprising fines, filler and bitumen.

- **Fine Gap Graded Asphalt (FGGA)**

Fine gap graded mixes are a modified form of dense graded mix specifically developed to achieve durable asphalt mixes for use in light traffic areas such as residential streets and lightly trafficked roads .

- **Ultra-Thin Asphalt (UTA) Surfacings including Thin Open Graded Asphalt.**

Ultra-thin asphalt surfacings have been developed as a means of restoring surface characteristics of otherwise sound pavements with the shape correction and surface properties of asphalt but with a minimal thickness of asphalt.

Ultra-thin asphalt surfacings are of two major types:

- Thin open graded asphalt placed with a modified asphalt paver that applies a binder layer immediately ahead of the asphalt layer, and
- Modified, small sized dense graded asphalt mixes.

Detailed descriptions of these mix types and guidelines for the selection of mixes for particular applications can be gained from AUSTROADS 1998a (17).

Steel furnace 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 of steel furnace slag aggregates.

## 4.3 The Advantages of Steel Furnace Slag Aggregate in Asphalt.

The properties of steel furnace slag aggregate that can be advantageously used in asphalt are:-

a) Cubical particle shape and 100 percent fractured faces provide strong aggregate interlock and improves resistance to permanent deformation under traffic.

b) High particle strength combined with cubical particle shape and abrasion resistance makes steel furnace slag aggregate suitable for wearing surface applications such as dense graded asphalt, stone mastic asphalt and open graded asphalt, even in heavily trafficked applications.

c) High skid resistance makes steel furnace slags suitable for wearing surface applications in high stress situations.

d) The strong affinity for bitumen and the high resistance to stripping makes steel furnace slag aggregates suitable for use in asphalt where conditions are encountered where stripping may occur.

e) The use of modified binders with steel furnace slag aggregate in asphalt can be effective in providing mixes that are resistant to bleeding and rutting in high stress situations. Guidelines for the selection and use of modified binders can be found in AUSTROADS 1998b (18).

Case studies illustrating the use of steel furnace slag aggregates in asphalt are provided in Section 7.

Detailed guidelines on how to incorporate steel furnace slag aggregates into the design of asphalt are provided in Section 5.

# 5. ASPHALT MIX DESIGN USING STEEL FURNACE SLAG AGGREGATES

## 5.1 Overview

Mix design for asphalt containing steel furnace slag aggregates is very similar to mix design for asphalt containing other aggregates. Some allowances however need to be made for the higher density of steel furnace slag. For example, the bitumen content expressed as a percentage of the total mix, will be slightly more on a volume basis as for asphalt containing naturally occurring aggregates but will be slightly less on a mass basis due to the higher particle density of the steel furnace slag aggregate.

The AUSTROADS Pavement Research Group (APRG) in May 1997, published "Selection and Design of Asphalt Mixes: Australian Provisional Guide" (19). Mix designs should be undertaken in accordance with this Guide.

## 5.2 Target Grading

The target grading will depend upon the end use of the asphalt. AUSTROADS Guide to the Selection of Road Pavement Surfacings (17) and local practice can be used to determine the appropriate maximum particle size or nominal size of the asphalt. The grading will depend upon the traffic loading, underlying materials, type of bitumen to be used and the local environment.

To make up the required target grading, coarse aggregate, fine aggregate and filler are graded and then a blended design is formulated. The blending of the constituent materials may take place at the steel furnace slag supplier's depot or alternatively individual particle sizes may be supplied to the asphalt producer's plant.

## 5.3 Bitumen Content

The selection of bitumen content is often based upon experience with similar mixes. It may also be based on achieving a minimum bitumen film thickness. The calculation for binder film thickness is presented below. For steel furnace slag aggregate, its higher particle density needs to be taken into account.

Once a trial binder content has been selected then a trial mix may be batched at binder contents ± 0.5% of the target. Compactions at varying numbers of cycles of the Gyratory Compactor are performed and the bulk density and air voids are plotted against Gyratory Compactor cycles.

The following parameters are also measured and plotted against binder content for the appropriate number of Gyratory Compactor cycles for the traffic category:

- air voids
- bulk density
- Voids in Mineral Aggregate (VMA)
- Voids Filled with Binder (VFB).

### Binder Film Thickness Calculation

$$F = \frac{Q_{EB}}{100 - Q_{BIT}} \frac{1}{A} \frac{10^3}{\rho_{BIT}}$$

Where

$F$ = film thickness (µm)

$Q_{EB}$ = effective binder content (% by mass of mix)

$Q_{BIT}$ = total binder content (% by mass of mix)

$A_c$ = surface area of aggregate blend - corrected for density($m^2$/kg)

$\rho_{BIT}$ = density of binder at 25°C ($t/m^3$)

The surface area of the aggregate is calculated from:-

TA = (2 + 0.02a + 0.04b + 0.08c +0.14d +.0.30e + 0.60f + 1.60g) x 0.20482

A = (TA x 2.65)/ $\rho_{COMP}$

$\rho_{COMP}$ = combined particle density of components

A = surface area of aggregate ($m^2$/kg)

a = percentage passing 4.75 mm sieve

b = percentage passing 2.36 mm sieve

c = percentage passing 1.18 mm sieve

d = percentage passing 0.60 mm sieve

e = percentage passing 0.30 mm sieve

f = percentage passing 0.15 mm sieve

g = percentage passing 0.075 mm sieve

## 5.4 Resistance to Stripping

Steel furnace slags have a strong affinity for bitumen. This is due in part to the presence of hydrated lime on the surface of weathered steel furnace slag aggregates. Hydrated lime is added to bitumen to promote resistance to stripping. With weathered steel furnace slag the hydrated lime is already present on the surface of the aggregate where it is needed.

AUSTROADS has been investigating a testing procedure for resistance to stripping or moisture damage for some time. At present, the Modified Lottman procedure is the most widely used in Australia (19).

Results from tests performed on asphalt containing steel furnace slag under the Modified Lottman procedure, RTA T640 (14), shows that steel furnace slag aggregates have a high resistance to stripping. Results are usually over 95% for the ratio of indirect modulus (wet/dry) for asphalt containing steel furnace slag as both coarse and fine aggregate. Current specifications have a minimum requirement of 80%.

Field performance in regard to stripping or moisture damage of asphalt containing steel furnace slag has been very good.

## 5.5 Moduli Values

The moduli of mixes are often obtained, particularly for medium to heavily trafficked roads. The range of modulus values for full slag mixes, tested in accordance with AS2891.13.1(20), is between 3,000 and 7,000 MPa. The conditions for this test represent a temperature environment of 25$^{o}$C and a vehicle travel speed of about 25 km/h. The test results need to be corrected to give modulus values for other temperature and design speed values.

These values are well above those usually assumed for design of pavement layers.

## 5.6 Sample Mix Design

A sample mix design is shown in the table 5.1. Other mix designs are provided in Section 7 - Case Studies

These are provided to show some of the characteristics of asphalt containing steel furnace slag aggregates.

### Table 5.1 - Dense Graded 14mm Asphalt

| Test Methods | | Results | Production Tolerances |
|---|---|---|---|
| AS 2891.2.2 (21)<br>AS 2891.9.2 (22) | 120 Cycles<br>Bulk Density (t/m$^3$) | <br>2.798 | |
| RTA T605 (23) | Max Density (g/ml) | 2.931 | |
| AS2891.8 (24) | Air Voids (%)<br>V.M.A. (%)<br>V(f)B (%) | 4.5<br>17.0<br>73.6 | 3.0 to 6.0<br>MIN 15% |
| AS2891.2.2 (21)<br>AS2891.9.2 (22)<br>AS2891.8 (24) | 350 Cycles<br>Bulk Density (t/m$^3$)<br>Air Voids (%) | <br>2.855<br>2.6 | <br><br>> 2.5% |
| RTA T607 (25) | Bitumen Content (%) | 4.9 | 4.8 - 5.4 |
| RTA T607 (25) | Combined Aggregate Grading<br>37.50 mm<br>26.50 mm<br>19.00 mm<br>13.20 mm<br>9.50 mm<br>6.70 mm<br>4.75 mm<br>2.36 mm<br>1.18 mm<br>0.600 mm<br>0.300 mm<br>0.150 mm<br>0.075 mm | <br><br>100<br>100<br>100<br>97<br>84<br>78<br>62<br>39<br>25<br>18<br>12<br>7<br>4.7 | <br><br><br><br>100<br>88-98<br>75-89<br>65-79<br>51-65<br>33-41<br>20-30<br>12-22<br>8-16<br>4.0-9.0<br>3.0-6.0 |
| RTA T607 (25) | Filler to binder ratio (%) | 0.9 | 0.6-1.2 |
| | Bitumen film thickness (µm) | 11.5 | > 7.5 |
| | Temp. of sample | 162 | |

# 6. USE OF STEEL FURNACE SLAG IN THIN BITUMINOUS SURFACINGS

## 6.1 General

This section describes the types of thin bituminous surfacings that can incorporate steel furnace slag aggregates. The types of surfacings described include sprayed bituminous surfacings and those applied as a slurry.

## 6.2 Types of Sprayed Bituminous Surfacings

The types of sprayed bituminous surfacings commonly used that could incorporate steel furnace slag aggregates are:-

- **Primerseals**

A primerseal is an initial treatment where a primerbinder is sprayed onto a prepared pavement surface and is covered with a layer of aggregate. It allows immediate trafficking, and allows for the delay in placing the final surfacing for logistical or operational reasons. Primerseals are generally only designed for a short life.

- **Seals and reseals**

A seal is formed by the spraying of one or more applications of binder and covering it with one or more layers of aggregate.

- **Special application seals**

*Strain Alleviating Membranes (SAMs)*

A Strain Alleviating Membrane (SAM) is a sprayed seal surfacing with a binder containing a relatively large amount of rubber or polymer modifier. It is used to absorb strains that occur in the pavement and reduce reflection cracking.

*Strain Alleviating Membrane Interlayers (SAMIs)*

A strain alleviating membrane interlayer (SAMI) is similar to a SAM but placed as an interlayer under asphalt.

*High Stress Seals (HSS)*

A High Stress Seal (HSS) is a bituminous seal, or reseal treatment that is subject to heavier than normal traffic loading due to braking, accelerating or turning vehicles.

Polymer Modified Binders (PMBs) are often utilised in SAMs, SAMIs and HSS to gain enhanced performance.

- **Reinforced seals**

*Fibre reinforced seals*

Fibre reinforced seals usually use a polymer modified emulsion and the application process uses a purpose-built sprayer which, on a single pass:-

- Sprays binder onto the pavement,
- Cuts the required amount of fibre glass to length, generally in the range 50mm to 90mm, and blows this onto the first layer of binder,
- Sprays a second layer of binder over the cut fibres,

The bitumen and fibre layers are immediately covered with a lightly spread aggregate which is locked into place using a racked in aggregate.

*Geotextile Reinforced Seals*

The two common types of geotextile reinforced seal are:-

- single coat (often using a modified binder)
- double coat (using modified or unmodified binder in the first spray of binder and slightly or unmodified binder in the second layer)

Geotextile reinforced sprayed seals are produced by spraying a layer of bitumen onto a pavement (bond coat), then covering this bitumen with a layer of geotextile and lightly rolling.

A single or double application seal is then applied over the geotextile.

## 6.3 Types of Slurry Surfacings

There are two basic types of slurry surfacings; a basic slurry mixture usually known as slurry seal and an enhanced mixture which is usually designated microsurfacing.

- **Slurry Seals**

Slurry seals are composed of a graded mixture of sand and fine aggregate containing filler, cement and unmodified bitumen usually in the form of an anionic emulsion and are generally placed in thicknesses around 1 to 1.5 times the nominal mix size. The maximum size of materials in a slurry seal varies from sand to 7mm aggregate (26).

- **Microsurfacing**

Microsurfacing is similar to slurry sealing except that polymer modified bitumen emulsions are used to provide faster setting for earlier trafficking, greater resistance to rutting, greater durability and improved flexibility. Larger sizes of aggregate and multiple applications are also feasible. Other terms for microsurfacing include microasphalt, cold overlay and microseal.

## 6.4 Use of Steel Furnace Slag Aggregate in Thin Bituminous Surfacings

Steel furnace slag aggregates can be incorporated into any of the above thin bituminous surfacing applications as an alternative to natural aggregates or to take advantage of the unique properties of steel furnace slag aggregates.

The properties of steel furnace slag aggregates that are advantageous when utilised in thin bituminous surfacings seals are:-

a) High aggregate strength, which limits aggregate breakdown and minimises flushing and moisture ingress.

b) High abrasion resistance and skid resistance, which makes steel furnace slag aggregate suitable for use in sprayed seals in high stress areas.

c) Cubical aggregate shape with a high percentage of fractured faces which makes steel furnace slag aggregate suitable for multiple application sprayed seals as it assists in the “locking up” of the aggregate.

In utilising steel furnace slag aggregate in sprayed seal applications, the spread rate of aggregate in $m^2/m^3$ is the same as for comparable naturally occurring aggregates but the higher density of the steel furnace slag aggregates needs to be accounted for in assessing the mass of aggregate required.

As with all materials the use of steel furnace slag aggregate needs to be evaluated on a value for money basis.

# 7. CASE STUDIES

## 7.1 BHP Steelworks Road System - Port Kembla

### 7.1.1 General

Asphalt containing steel furnace slag has been produced since 1980 at the Boral Asphalt Plant, which is situated within the BHP Port Kembla Steelworks. For that period asphalt containing steel furnace slag was used in all types of applications within the steelworks areas and continues to be used throughout the works.

Since 1990, following the proven performance of steel furnace slag asphalt's, asphalt containing steel furnace slag has been used on roads for Councils, the Roads and Traffic Authority and civil contractors (27).

The BHP internal road network consists of over 20 km of roads that have been constructed from slag materials. Some 6 km of the network was constructed or reconstructed during 1990/91. These roads were constructed from blast furnace slag roadbases and surfaced with asphalt containing steel furnace slag.

### 7.1.2 Asphalt Mix Design

Asphalt for the steelworks road system was designed using conventional methods and incorporated as much steel furnace slag as possible. All aggregate fractions down to 7 mm were steel furnace slag. The remainder of the grading was made up from steel furnace slag fines and/or quarry produced fines e.g. . basalt and sand.

The bitumen used was C320 with no added polymers or other modifiers.

A typical mix is as shown in Table 7.1.

**Table 7.1 - Typical Asphalt Properties for a Dense Graded 14mm Mix Containing 55% Steel Furnace Slag**

| | |
|---|---|
| Aggregate Grading | |
| % passing AS sieve 19.0mm | 100 |
| % passing AS sieve 13.2 mm | 99 |
| % passing AS sieve 9.5mm | 91 |
| % passing AS sieve 6.7 mm | 73 |
| % passing AS sieve 4.75 mm | 56 |
| % passing AS sieve 2.36 mm | 47 |
| % passing AS sieve 1.18 mm | 36 |
| % passing AS sieve 600 µm | 29 |
| % passing AS sieve 300 µm | 18 |
| % passing AS sieve 150 µm | 9 |
| % passing AS sieve 75 µm | 6.7 |
| Bitumen Content - Dry Aggregate Total Mix | 5.5%5.2% |
| Voids | 5.5% |
| Voids filled by bitumen | 71.1% |
| Briquette Density | 2.683 kg/m$^3$ |
| Maximum Density | 2.838 kg/m$^3$ |

### 7.1.3 Pavement Design and Loading

Pavements within the steelworks area were constructed using slag roadbases. During the construction of pavements in 1990/91 blended roadbase consisting of 60% steel furnace slag and 40% granulated blast furnace slag was used for most of the roadways. This material gains sufficient strength through reaction of lime and slag to give unconfined compressive strengths in the range of 4 to 8 MPa. It is thus considered to be a heavily bound material with modulus values over 5,000 MPa as calculated using the formulas in the AUSTROADS Guide to the Structural Design of Road Pavements (1992), Section 6.3.2.3 Modulus Correlation's (28). Therefore these pavements have deflections of less than 0.2 mm and very low curvatures of less than 0.06 mm.

Most subgrade within the steelworks area is either sand or various slags. Hence the subgrade CBR is greater than 10 in most areas.

Asphalt placed over heavily bound material is subject to high compressive stresses due to the very low deformation of the base layer. This makes rutting or other deformation of the asphalt the most likely failure mechanism, particularly if slow moving vehicles with heavy wheel loadings are using the pavement. Fatigue of asphalt surfacing on a heavily bound pavement is unlikely to occur provided that a good bond is achieved between asphalt and base. Any failure is most probably a result of fatigue in the base layer.

The movement of large amounts of materials within the steelworks is facilitated by vehicles capable of carrying heavy loads. These vehicles impart very high axle and wheel loads on the asphalt surfacing, as shown in Table 7.2. These loads are generally applied at low speeds. All vehicles are required to travel at less than 50 km/h and the larger vehicles at less than 30 km/h.

Some 2,000,000 tonnes of slag are moved annually on these roads as well as various metallics and water carts. There are also movements of Cat 992 loaders whose tyres are protected by chains. Very high local stresses occur under the chains necessitating high deformation and abrasion resistance from any asphalt pavements.

There is also the movement of 1,500,000 tonnes of coal into the Port Kembla Steelworks area and the movement of 1,000,000 tonnes of processed slag products over these pavements in triaxle semi-trailers.

Within the steelworks area there are three major roundabouts, which are used regularly by the heavily loaded vehicles. Very high stresses are placed on the asphalt wearing surface as high wheel and axle loads pass over these sections.

### 7.1.4 Wearing Surface Performance

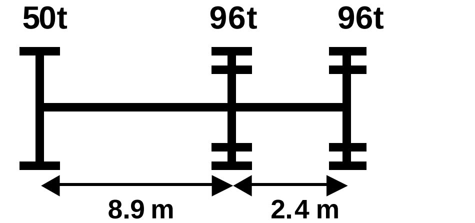
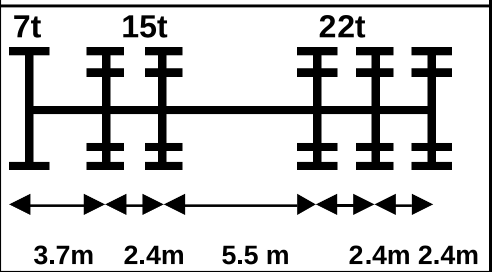
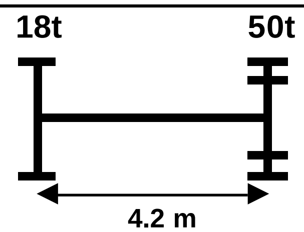
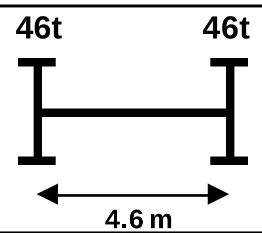
When due consideration is given to the high traffic loads within the road network of the Works, inspections have not revealed any areas of significant deformation or rutting on asphalt. Even within roundabout areas there have not been any degradation due to rutting or shoving. This demonstrates the high deformation resistance of asphalt containing steel furnace slag aggregate. Some widely spaced shrinkage cracking does appear in the pavements but this has had no adverse effect on the performance of the asphalt. There is also some crocodile cracking present in high stress areas indicating that the bound base/subbase may be nearing the end of its design life.

## 7.2 Roads and Traffic Authority - Illawarra District

Roads maintained by the Roads and Traffic Authority's Illawarra District Office are used by many triaxle semi-trailers transporting coal to Port Kembla for steelmaking and export. The same roads carry much of the industrial produce from the Wollongong area. Most of the triaxle semi-trailers are able to carry the maximum legal load through the use of permits and many are using 'super single' tyres which have higher contact pressures and hence increased damaging effect.

To carry these high loadings it has been necessary to construct heavily bound or deep lift asphalt pavements. In both cases these pavements have asphalt wearing surfaces. The high loading and low deflection pavements create conditions which increase the susceptibility of asphalt to deformation through rutting or shoving.

**Table 7.2 - Typical Design Axle Loads used for roads within BHP - Port Kembla**

| Vehicle Type | Gross Axle Loading And Configuration |
|---|---|
| Elevated Platform Carriers |   |
| Highway Trucks |   |
| Euclids |   |
| Caterpillar 992 |   |

**Picton Road, Wilton**

On some sections of pavement where the large number of heavy vehicles were braking and turning it was decided to trial asphalt with steel furnace slag aggregate during the early 1990's. After initial successful trials asphalt containing steel furnace slag became accepted for many situations.

### 7.2.1 Intersection of F6 - Freeway and Northern Distributor - Wollongong

The intersection of the F6 - Freeway and the Northern Distributor at Gwynneville known as "Crystal Corner" has an Annual Average Daily Traffic of 50,000 vehicles with an estimated percentage of commercial vehicles of 20%. Previously traffic lights controlled the intersection and southbound traffic was required to stop or slow down prior to turning right onto the Northern Distributor. The regular stopping of the vehicles and acceleration through the intersection resulted in high stresses being imparted onto the asphalt surface. This section has flat terrain prior to and through the intersection.

During the 1980's and early 1990's a number of wearing surface treatments were placed on the approaches to Crystal Corner and through the intersection. All needed to be replaced after relatively short periods due to deformation.

A 14mm dense grade asphalt containing steel furnace slag aggregate was placed in 1992. The binder was C320 bitumen with 5% gilsonite. Gilsonite hardens the binder and increases rut resistance. This wearing surface performed well up to 1998 when it was replaced during the construction of a grade separated intersection. In evidence of the materials suitability and performance characteristics, steel furnace aggregates were again selected for the new works

### 7.2.2 Other Roads within the Network

Other sections of the Highway Network have also been surfaced with asphalt containing steel furnace slag. This has been done to increase skid resistance in areas with high accident rates and to increase deformation resistance. Various binders have been used as shown in Table IV. Early SCRIM results for these sections are encouraging. On Bulli Pass the SCRIM testing has given mean results in the range 0.73 to 0.85 after 2.5 years.

**Princes Highway, Bulli Pass**

This is an excellent result. It is realised that continued monitoring will be required for assurance of long term performance.

Table 7.3 indicates sections of the network which have been surfaced with asphalt for performance reasons. Many other sections have been surfaced with asphalt containing steel furnace slag because steel furnace slag is the most economic aggregate.

These sections are mainly 14 mm dense grade mixes although Macquarie Pass includes a Stone Mastic Asphalt (SMA) section with nominal size 10 mm.


**Princes Highway, Helensburgh**

### 7.2.3 Asphalt Mix Designs

The predominant mix used by the RTA is 14 mm dense grade and typical blend proportions are shown in Table 7.4. A blended 14 mm steel furnace aggregate has been mixed with sand, filler (flyash) and bitumen, which in the typical mix shown is of type AR 320/1000. AR 320/1000 has similar properties to C600 bitumen at high temperatures for deformation resistance and also has fatigue characteristics of C170 bitumen at low temperatures. It is also known as "Multigrade" bitumen. The RTA has also made 20 mm dense grade and 10 mm open grade mixes containing steel furnace slag.

Mixing in accordance with the proportions shown in Table 7.4 gives a mix with typical properties as shown in Table 7.5. This mix has been reported to give excellent results when compacted using the gyratory compactor for 350 cycles. The percentage of voids remaining in the asphalt after this number of cycles has been 2.5 or greater. This indicates a mix that is very unlikely to deform.

## 7.3 Pennant Hills Road

A number of sections of Pennant Hills Road between Carlingford and Pennant Hills in Sydney are surfaced with asphalt containing steel furnace slag. There is also one section that consists of a nominal 200 mm of asphalt over lean mix concrete.

Pennant Hills Road is a very heavily trafficked road with some of it on a steep grade. There are frequent intersections, which are controlled by traffic lights. During the 1990's the road has been widened, intersections improved and new pavements constructed. This initially led to a

### Table 7.3 - The Binder used on Sections of the Highway Network where Asphalt contains Steel Furnace Slag

| Section | Binder |
|---|---|
| Angels Creek, Corrimal | C320 + 5% Gilsonite |
| Kerang Ave to Rothery Road, Woonona | C320 + 5% Gilsonite |
| Bulli Pass | AR 320/1000 Bitumen |
| Helensburgh Curves | AR 320/1000 Bitumen |
| Picton Road Climbing Lane | AR 320/1000 Bitumen |
| Mt Ousley to Picton Road Turning Lane | AR 320/1000 Bitumen |
| F6 – Northern Distributor Intersection | AR 320/1000 Bitumen |
| Macquarie Pass | AR 320/1000 Bitumen |
| Cambewarra Mountain and Barrengarry Mountain – Kangaroo Valley | AR 320/1000 Bitumen |

### Table 7.4 - Typical mix proportions for 14mm Dense Graded Asphalt Mix

| Product | Percentage |
|---|---|
| 14mm blended steel furnace slag aggregate | 87.9 |
| Sand | 5.0 |
| Filler – flyash | 2.5 |
| Bitumen - type AR 320/1000 | 4.6 |

### Table 7.5 - Typical Asphalt Properties for a Dense Graded 14mm Mix

| | |
|---|---|
| **Aggregate Grading**% passing AS sieve 19.0 mm | 100 |
| % passing AS sieve 13.2 mm | 97 |
| % passing AS sieve 9.5 mm | 84 |
| % passing AS sieve 6.7 mm | 71 |
| % passing AS sieve 4.75 mm | 56 |
| % passing AS sieve 2.36 mm | 43 |
| % passing AS sieve 1.18 mm | 30 |
| % passing AS sieve 600 m | 23 |
| % passing AS sieve 300 m | 12 |
| % passing AS sieve 150 m | 5.7 |
| % passing AS sieve 75 m | 4.0 |
| Bitumen Content | 4.6% |
| Voids | 5.0% |
| Voids filled by bitumen | 70.3% |
| Briquette Density | 2.786 kg/$m^3$ |
| Maximum Density | 2.932 kg/$m^3$ |

number of problems with deformation and rutting of wearing surfaces.

Steel furnace slag was used by Boral Asphalt in the wearing surface of a number of sections as a means to improve the resistance to deformation and rutting.

CSR Emoleum constructed the pavement at the intersection of the M2 Motorway on Pennant Hills Road. This consists of three nominal 60 mm layers of 20 mm dense grade asphalt. Steel furnace slag was used as both the coarse and fine aggregate.

## 7.4 Tomerong Bypass

Steel furnace slag aggregate was chosen for the asphalt surfacing of Tomerong Bypass, South of Nowra on the Princes Highway in NSW. In 1996 a thin (nominal 20 mm) 10 mm open grade asphalt layer over a rubberised bitumen seal was placed on the existing pavement. This low cost treatment provided improved ride, skid resistance and waterproofing. Steel furnace slag was chosen because of its shape and skid resistance properties as well as meeting all other specification requirements.

In an open grade mix using a strong well shaped aggregate allows for an improved matrix with good aggregate interlock for load dispersion and transfer.

Some 7 km of single carriageway were resurfaced and the use of steel furnace slag in thin asphalt has become more widely accepted.

The wearing surface has performed well to date.

## 7.5 Roberts Road, Padstow

CSR Emoleum used steel furnace slag aggregates in the wearing surface of Roberts Road at Padstow in Sydney. A 30 mm layer of 10 mm open grade asphalt was placed and the coarse aggregate consisted of 10 mm steel furnace slag. Steel furnace slag was chosen for its skid resistance properties as well as its shape.

The paving of the wearing surface took place in 1997 and after to date there is no sign of any deterioration.

## 7.6 The Newcastle Region

### 7.6.1 Newcastle BHP Steelworks

Steel furnace slag aggregate asphalt's have been used in the past throughout the Newcastle area (29). Newcastle BHP steelworks was one of the first sites in which slag asphalt's were trialed in the region.

Trials using steel furnace slag in asphalt mixes were commenced in 1987. Due to the steel furnace slag's success, approximately 3 kms of pavement have been reconstructed around the works in areas subjected to severe traffic stress. This includes major haul roads, intersections and areas of localised braking and accelerating. It should be noted here that base pavements have also been constructed using slag materials. Typical designs for 10mm and 14mm asphaltic concrete are as given in Table 7.6.

An asphalt trial in 1992 was carried out within BHP in conjunction with the RTA (30). The section of road was constructed to service heavily laden trucks carting iron ore to stockpiles. The trial enabled the comparison of the performance of a number of different high strength asphalt designs. The results indicated that given the strength characteristics of steel furnace slag asphalt, the slag asphalt performs as well as the high strength mixes and mixes that had the addition of Gilsonite.

**Table 7.6 - Typical Mix Designs - BHP Newcastle Steelworks**

| | | 14mm Asphalt | 10mm Asphalt |
|---|---|---|---|
| **Size** | **Material** | **% in mix** | **% in mix** |
| 14mm | Steel furnace slag | 21.9 | - |
| 10mm | Steel furnace slag | 12.9 | 26.9 |
| 5/7mm | Steel furnace slag | 17.0 | 12.8 |
| Dust | Crusher dust | 28.4 | 37.1 |
| Sand | Dune / river | 11.8 | 14.4 |
| Filler | Flyash | 2.5 | 2.8 |
| Bitumen | C320 | 5.5 | 6.0 |

### 7.6.2 Kooragang Island

Trials have been carried out on Kooragang Island to test steel furnace slag asphalt's as well as slag base courses. The trial site was an industrial waste disposal area and, as such, the majority of traffic was heavily laden vehicles.

The project involved the reconstruction and sealing of approximately 1km of road. The pavement was completed in April 1992 and has been subject to more than 200 truck movements per day. An all steel furnace slag 10mm asphalt was laid at a thickness of 35mm. The area chosen was the access way to levy banks. The main section of pavement has shown some longitudinal cracking associated with sub pavement layer movements. High lateral forces from trucks occur at a turn off area where the steel furnace slag asphalt has performed very well.

### 7.6.3 New England Highway

With the RTA involvement in the successful trial asphalt pavements on BHP land, a full trial section was carried out on the New England Highway. The trial was situated at Hexham at the beginning of the New England Highway and is approximately 1.3km long, with a traffic count of 34,500 vehicles per day (1992) on this road. Two control pavements were also placed to compare steel furnace slag to proven crushed rock asphalt mixes. Andesite aggregate and Rhyolite aggregate were used as control pavements.

The trial was a rehabilitation of a divided carriageway constructed on a low embankment on a flat grade. The existing asphalt was removed and 60mm of steel furnace slag AC 20 asphalt placed followed by 40mm of AC 14 wearing surface incorporating the two control sections. Mix parameters for these pavements are shown in Table 7.7.

Class 170 binder was used with variations as required for the known aggregate characteristics.

An objective of the testing was to assess the skid resistance of the steel furnace slag mix. SCRIM testing has shown the steel furnace slag to be performing equal to that of the control pavements in all properties, and better than the control pavements from a serviceability point of view.

**Table 7.7 - Mix parameters used for the New England trials**

| | Mix Description (all dense graded) | | | |
|---|---|---|---|---|
| **AS Sieve Size (mm)** | **14mm Steel furnace slag** | **14mm Andesite** | **14mm Rhyolite** | **20mm Steel furnace slag** |
| 26.5 | | | | 100 |
| 19.0 | 100 | 100 | 100 | 92-100 |
| 13.2 | 92-100 | 92-100 | 92-100 | 80-94 |
| 9.5 | 73-87 | 73-87 | 71-85 | 65-79 |
| 6.7 | 55-69 | 59-73 | 58-72 | 52-66 |
| 4.75 | 48-62 | 54-68 | 51-65 | 45-59 |
| 2.36 | 40-50 | 46-56 | 43-53 | 37-47 |
| 1.18 | 29-39 | 37-47 | 33-43 | 28-38 |
| 600 µm | 23-31 | 30-38 | 26-36 | 22-30 |
| 300 µm | 12-20 | 16-24 | 16-24 | 12-20 |
| 150 µm | 5.5-10.5 | 7.5-12.5 | 6.5-11.5 | 7-12 |
| 70 µm | 4.9-7.9 | 6.8-9.8 | 7.4-10.4 | 6.0-9.0 |
| Bitumen Binder ( % of total mix by mass ) | 4.9 – 5.7 | 5.0 – 5.8 | 5.1 – 5.9 | 4.5 – 5.3 |
| Voids | 4.7 | 4.7 | 4.7 | 4.7 |
| Stability | 16-40 | 16-40 | 16-40 | 16-40 |
| | **SCRIM TEST RESULTS** | | | |
| On curve[1] | 0.42 – 0.58 (mean 0.50 sd 0.05) | | 0.41 –0.67 (mean 0.53 sd 0.08) | |
| On straight[1] | 0.50 – 0.62 (mean 0.56 sd 0.04) | 0.45 – 0.59 (mean 0.52 sd 0.05) | | |

[1] After 2 to 3 years

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# 9. COMMON INDUSTRY ACRONYMS & ABBREVIATIONS

| | |
|---|---|
| AC | Asphaltic Concrete |
| ALD | Average Least Dimension |
| ARRB | Australian Road Research Board |
| BF | Blast Furnace |
| BOS | Basic Oxygen Steel |
| CGGA | Coarse Gap Graded Asphalt |
| DGA | Dense Graded Asphalt |
| DGB | Dense Grade Base |
| DGS | Dense Grade Sub-base |
| EAF | Electric Arc Furnace |
| FGGA | Fine Gap Graded Asphalt |
| GBFS | Granulated Blast Furnace Slag |
| GGBFS | Ground Granulate Blast Furnace Slag |
| GP | General Purpose Cement |
| HSS | High Stress Seal |
| LH | Low heat Cement |
| OGA | Open Graded Asphalt |
| OPC | Ordinary Portland Cement |
| PAFV | Polished Aggregate Friction Value |
| RTA | Roads & Traffic Authority, NSW |
| SAM | Strain Alleviating Membrane |
| SAMI | Strain Alleviating Membrane Interlayer |
| SBC | Slag Blended Cement |
| SCRIM | Sideways Force Coefficient Routine Investigation Method |
| SMA | Stone Mastic Asphalt |
| SR | Sulphate Resisting Cement |
| SSD | Saturated Surface Dry |
| SSF | Steel Slag Fines |
| UCS | Unconfined Compressive Strength |
| VFB | Voids Filled with Binder |
| VMA | Voids in Mineral Aggregates |

# 10. GLOSSARY OF TERMS

### Aggregates

Material complies with the specified Grading requirements for fine and coarse aggregates. It may be produced from rock, gravel metallurgical slag or artificial stone.

### Asphalt (Hot Mix)

A mixture of bituminous binder and aggregate with or without mineral filler produced hot in a mixing plant. It is delivered, spread and compacted while hot. The term Asphalt which is in common use in Australia, is an abbreviation for Asphaltic Concrete.

### Bound Pavements

Pavements composed of granular materials incorporating sufficient amounts of binding agent(s) to produce significant flexural stiffness.

### Coarse Aggregates

Material having a nominal size of not less than 5mm and complying with the requirements Australian Standard AS1141.11 (31).

### Cubical Aggregates Particles

An aggregates particle which is approximately cube-shaped.

### Fine Aggregates

Material having a nominal size of less than 5mm and complying with the requirements Australian Standard AS1141.11 (31).

### Grading (Aggregates)

The proportion of the various particle sizes present in an aggregate, expressed as a percentage by mass of the whole.

### Heavily Bound Base

A bound pavement layer having a Unconfined Compressive Strength (UCS) value greater than 4 MPa.

### Mat

A surface condition in which the aggregate is proud of the surface and the binder is approximately two thirds of the way up the sides of the aggregate particles.

### Polished Aggregate Friction Value

A measure, on scale of 0 to 100, of the resistance of an aggregate to polishing under the action of traffic as determined in standard laboratory tests.

### Polishing

A condition whereby the surface of an aggregate becomes smooth under the action of traffic. This tends to reduce tyre/road friction.

### Precoating

The coating of an aggregate with an oil, water of bituminous based material, with or without an adhesion agent, to suppress the dust and improve the subsequent adhesion of bituminous material.

### SAM (Stain Alleviating Membrane)

A sprayed seal with the binder containing a relatively large concentration of rubber or polymer modifier. It is used to provide a membrane to absorb strains that occur in a road pavement and thereby reduce reflection cracking.

### SAMI (Stain Alleviating Membrane Interlayer)

Similar to SAM, but provided as an interlayer before placing an Asphalt overlay (usually a thicker and more highly modified binder than a SAM)

### Skid Resistance

The frictional resistance provided by the pavement surface to the vehicle tyres during braking of cornering manoeuvers. It is usually measured on wet surfaces.

### Sprayed Seal

A thin surface layer of bituminous material covered with aggregate which, as the uppermost pavement layer, is directly subjected to the forces of vehicular traffic.

### Vesicular Slag

The term vesicular as applied to slag means the particles contain voids which tend to be unconnected to each other, occurring throughout each particle and appearing as blind holes on the particle surface.

### Weathered Steel Furnace Slag

Steel furnace slag is considered to be weathered when it has been exposed in its finished form to both atmospheric and controlled conditions to allow the full hydration of any lime present .

### Wearing Surface

That part of pavement upon which the traffic travels.

### Bleeding (seals)

A surface condition in which an excess of free binder completely covers the aggregate. There is no surface texture.

### Flushed Surface

A smooth pavement surface due to the presence of excess binder.

### Gyratory Compactor

A controlled method of compacting asphalt samples where an axial load is applied 1 to 3 degrees from the perpendicular as the sample rotates. Each application of the load is termed a cycle.

### Modulus (resilient)

The ratio of stress to recoverable strain under repeated loading conditions. Also referred to as elastic stiffness.

### Rutting

The longitudinal vertical deformation of a pavement surface in a wheel path, measured relative to a straightedge placed at right angles to the traffic flow and across the wheel path.

### Shoving

Lateral displacement of pavement structure by braking, accelerating or turning vehicles.

### Stripping

A separation of the binder film from the surface of aggregate, usually in the presence of water.

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