# Characterization of Electric Arc Furnace (EAF) Steel Slag for Unbound Applications

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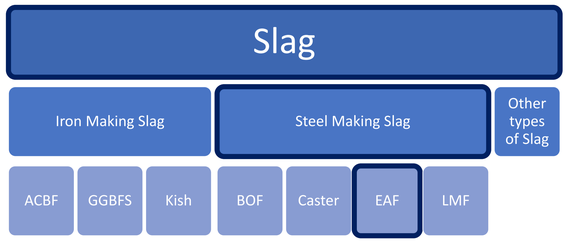
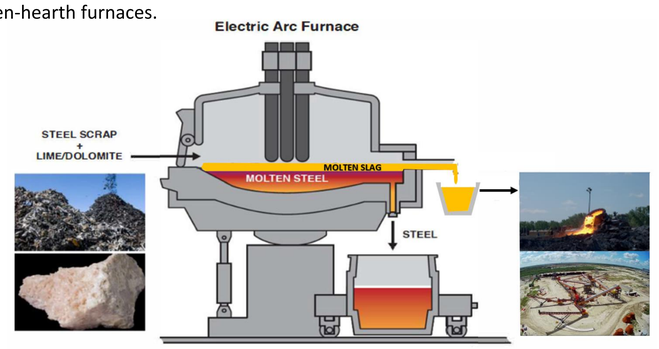
## What is EAF Steel Slag?




**ASTM D8: Standard Terminology Relating to Materials for Roads and Pavements**
**Steel slag,** *n*—the nonmetallic product consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium, that is developed simultaneously with steel in basic oxygen, electric, or open-hearth furnaces.




## Applications of EAF Steel Slag

Today the use of slag as aggregates in bound and unbound mixtures, particularly in road construction applications, is well established such that iron and steel slags not only rival similar natural aggregate but in some instance are considered superior materials based on specific properties.
Recognition of slag as a sustainable alternative to natural materials makes it an ecologically sound and economically intelligent use of this product.

| | | | |
|---|---|---|---|
| Construction Entrances | Road Base | Parking Lots | Embankment Fill |
| Culverts | Shoulders | Gabions | Railroad Beds |
| Erosion Control | Driveways | Asphalt Aggregate | Unpaved Trails |
| Trench Fill | Septic Fields | Soil Remediation | Rip Rap |
| Anti-Skid | pH Neutralizer | Agricultural Lime | Environmental Applications |
| Permeable Reactive Barrier | Hot Mix Asphalt | Portland Cement | |

## Characterization of EAF Steel Slag

It's important to remember that slag isn't slag, there are different types of slag that are produced depending on the manufacturing process. To ensure that EAF slag is being utilized in the appropriate applications, it must be characterized to ensure proper use and that it will meet the requirements of customers, specifiers, regulators and the different applications.

| MAJOR PRIMARY MINERAL CONSTITUENTS | MOLECULAR AND STRUCTURAL FORMULA |
|---|---|
| **larnite, beta-dicalcium-silicate** | beta-$Ca_2SiO_4$ |
| **srebrodolskite, calcium-iron-oxide** | $Ca_2Fe_2O_5$ |
| **brownmillerite, calcium-aluminum-iron-oxide** | $Ca_2AlFeO_5$ |
| **spinel** | $Me_2+Me_3+2O_4$ |
| **wuestite, solid solution of iron(II)-oxide with MgO and MnO** | $(Fe_{1-x-y}Mg_xMn_y)O_z$ |
| **gehlenite, calcium-aluminium-silicate** | $Ca_2Al_2SiO_7$ |
| **bredigite, calcium-magnesium-silicate** | $Ca_{14}Mg_2Si_8O_{32}$ |

- Specific gravity: 3.4 – 3.8
- Unit Weight: 1600-1920 kg/m$^3$ (100-130 lb/ft$^3$)
- Absorption: up to 3%
- Non-Liquid / Non-Plastic
- LA Abrasion: 18 to 30
- Sodium Sulfate Soundness: <12%
- Crush Count: Highly Irregular (80+ Two Face)
- Gradation: Meets ASTM (D1241) and FHWA (Type 1 or 2) Requirements
- Binding Potential: Free Lime in Excess of 6%*

**There are various types of Steel Slag. Not all have the ability to act as a binder in these applications. Proper characterization is essential.*

## Case Studies

### Partial Depth Reclamation & Secondary Road Stabilization – Noble County, IN

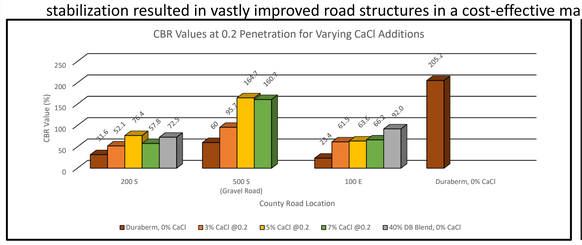
Noble County, IN is a mostly rural county with over 1000 miles of county roads maintained. Over the past decade, the county has utilized partial depth reclamation to reduce costs and extend the lifespan of the county roads, maintaining up to 15 miles in a year with this application.

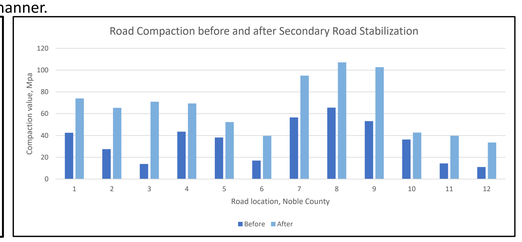
- A 50% blend of steel slag with existing aggregates is expected to increase the strength two-fold. Noble County typically utilizes a 30-40% blend range depending on the existing roadway and any modifications, such as widening or drainage, that may be factored into the construction.
- CBR data also showed a significant increase in the strength of the new mix when 40% steel slag was blended with the existing road aggregates.
- The goal of the project was to improve the existing roadway with the least amount of slag and calcium chloride additions. At a 40% blend, all three road materials when blended with 3 % calcium chloride achieved greater than 50% CBR.
- Light Weight Deflectometer (LWD) compaction results indicated that a 40% addition in aggregate provided a more than 200% increase in many of the samples. Overall, the stabilization resulted in vastly improved road structures in a cost-effective manner.



| Unconfined Compression | | |
|---|---|---|
| | No Aging | 28 Day |
| Existing Roadway | 23.0 psi | 46.5 psi |
| W/ 30% Blend | 26.4 psi | 80.9 psi |
| W/ 40% Blend | 39.5 psi | 85.3 psi |
| W/ 50% Blend | 57.5 psi | 90.3 psi |
| W/ 60% Blend | 61.8 psi | 96.0 psi |

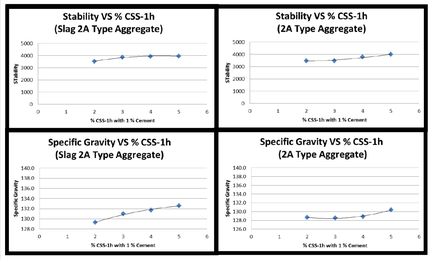
| California Bearing Ratio | | |
|---|---|---|
| | 0.1" Penetration | 0.2" Penetration |
| Initial | 25.1 PSI | 33.3 PSI |
| Final | 60.8 PSI | 81.1 PSI |



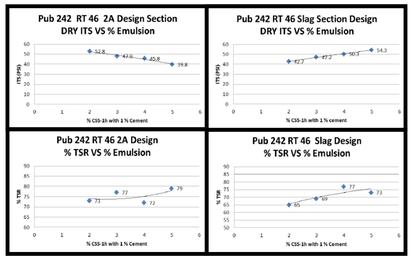




### Full Depth Reclamation: PennDot Project 2016

McKean county, Pennsylvania completed a full depth reclamation project on State Road 46, comparing Steel Slag Aggregate to a traditional natural aggregate. The project was 4.65 miles of two-lane highway with average daily traffic of 1,035 vehicles (376 trucks). The road was widened from twenty (20) to twenty-four (24) feet and utilized 6,500 tons of steel slag obtain the necessary structure for widening.




Shown above is stability and specific gravity data of a 2A Type natural aggregate compared to 2A Type slag, each with varying rates of the CSS binder containing 1% cement. The slag sample with 3% binder achieved the same stability as the natural aggregate with 5% binder.




Shown above, graphs depict the steel slag performing as well as the natural aggregate for ITS and TSR

Addition of aggregate to existing road.

Milling depth of 12" – existing and new aggregates blended

Result after compaction and rolling – wider roadway ready for asphalt

Final result after Full Depth Reclamation, 3" binder and 1.5" wearing course

## Conclusions

In summary, EAF steel slag is a versatile product that can be utilized in many applications. Due to the general application of the term slag to many manufacturing processes, it's important to characterize slag completely, looking at both the chemical and physical characteristics of the material. Risk assessments routinely demonstrate that these "slags pose no meaningful threat to human health or the environment when used in a variety of applications". Steel slags typically have high bulk density, excellent skid resistance and interlocking properties that give them a significant advantage over many aggregates for uses that require stable surfaces and a great bearing capacity. Free lime present in the aggregate may provide excellent binding potential for various applications – proper characterization of this component is necessary to ensure it meets the requirement of the application. The addition of EAF steel slag can result in sustainable, cost-effective improved road structures.

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