PELLETIZED LIGHTWEIGHT SLAG AGGREGATE

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SYNOPSIS

The pelletizing process and the use of pelletized lightweight slag in structural and masonry concrete is described. Pelletlzed expanded slag has significant production and usage advantages when compared to conventional expanded vesicular slag. The major current use of pelletized slag is in lightweight concrete blocks. Structural concrete applications have generally been in semi-lightweight mixes. Other uses such as in slag cement manufacture are outlined.

INTRODUCTION

By selective cooling of the relatively uniform molten slag that is a co-product of iron production (=0.20 to 0.30 kg slag/kg iron), three distinct types of blast furnace slag have been processed for many years: air-cooled, which finds extensive use in conventional aggregate applications; granulated, which is specifically produced in a vitrified state for slag cement manufacture; and expanded (or foamed as it is known in Europe), which is used mainly as lightweight aggregate in structural and masonry concrete.[1] A relatively new process, initially developed by National Slag Limited in Hamilton (Ontario) as a means of limiting the gaseous emissions associated with conventional expansion processes, involves pelletizing to produce a lightweight aggregate which is used in both concrete applications, and slag cement manufacture.[2,3] The process and product advantages of pelletized slag are now becoming recognized on an international level with 23 machines active in 9 countries (Australia, Canada, England, Finland, France, Luxembourg Sweden, United States, Wales). The pelletizing process and its features will be indicated, before focusing on the product and its use as a lightweight aggregate.

SLAG PELLETIZER

The basic action of the pelletizer with its spinning drum (Figures 1 and 2) is to take a pyro-plastic expanding slag, and chill it quickly in the dispersed form with air and water, so that hydrogen sulfide emissions are limited. To do this, a controlled slag flow (up to 3 t/min) is expanded under water sprays on a vibrating feed plate, and then passed over the internally-cooled spinning drum (280 rpm) where the 8 concave throwing vanes (Figure 1) break- up the now pyroplastic material and 'hurl' the slag into the air for a sufficient time that surface tension forms pellets (Figure 2). By controlling the process, a more crystalline pellet can be produced for aggregate applications, or a more vitrified pellet (increased drum speed and more cooling water) for cementitious applications.[2-5] Because of this rapid cooling, the pelletizer can be considered an 'air granulator'.

While gaseous emissions control was the early motivation for installing pelletizers (hydrogen sulfide reduced from 4000 ppm to 10 ppm in the hood[4], the prime reason for most installations now is the versatility of applications for the slag product. Other benefits of pelletizing as a slag handling process that have been demonstrated include: pellets can be re- moved immediately; space requirements minimized; low installation costs; and water conservation. The optimum conditions for pelletizing appear to be a uniform flow of basic slag that is as hot as possible, which favors a direct runner pelletizer(s) installed at the furnace (Figures 1 and 2).

PELLETIZED SLAG PROPERTIES

In following sections, the properties and use of pelletized slag as a lightweight aggregate will be described largely in terms of experience in Southern Ontario, and the relevant codes and standards in Canada (CSA, ACI, ASTM).For other areas and jurisdictions, local experience, the properties of the available pelletized slag, and relevant codes must of course be considered. Many of the properties of pelletized lightweight slag are similar to those for conventional expanded (foamed) slag. However, there are some important and favorable differences that should be outlined.

General Properties

Each pellet produced tends to be spherical with a relatively smooth, sealed surface (Figure 3). This tends to be a major product improvement in terms of workability, absorption and cement requirements, over the rough, vesicular surface (Figure 3) produced with conventional expansion processes. While pellets varying in size from 13 mm to 150 mm are produced, the bulk of the product is in the minus 10 mm to plus 1 mm range. Further processing is generally involved for lightweight aggregate applications; crushing some plus 6 mm material to provide for the minus 1 mm deficiencies in fine aggregate for lightweight concrete blocks, for example. Typical gradations and bulk densities of pelletized slag lightweight aggregate supplied for structural and masonry concrete are given in Table 1.

The pelletized slag generally has a higher bulk density (dry loose value of 840 kg/m^3 for coarse block aggregate, meeting the ASTM C331 maximum of 880 kg/m^3) than expanded vesicular slag (720 kg/m^3). However, it has been noted that the dry density of concrete masonry has not increased proportionately, and much of the density difference is probably test dependent. Crushing the pellets to reduce the tendency of surface to surface contacts decreases the tested bulk density by almost 80 kg/m^3, making it much closer to expanded vesicular slag[3].

TABLE 1 TYPICAL GRADATIONS AND BULK DENSITIES OF PELLETIZED LIGHTWEIGHT SLAG FOR STRUCTURAL AND MASONRY CONCRETE

Sieve Size	Percent Passing Coarse Structural	Block Coarse	Block Fine
12.5 mm	100		
9.5 mm	85	100	
4.75 mm	18	50	100
2.36 mm	2	5	80
1.18 mm			50
600 μm			30
300 μm			20
150 μm			10
Bulk Density kg/m^3 (loose, dry)	840	840	1070

Workability and Cement Requirements

There has been a noticeable increase in workability with the use of pelletized lightweight slag in both structural and masonry concrete mixes that is undoubtedly related to the spherical shape and smooth texture of the individual pellets (Figure 3). This manifests itself in the relative ease of placement of the plastic concrete, and freedom from cracking of green masonry after forming. Since the pellets tend to provide a minimum surface area, the quantities of cementitious materials required for a given compressive strength in structural and masonry concrete mixes are reduced approximately 20%. Much of this saving is probably due to freedom from loss of cement into external voids. The water absorption is also much reduced as indicated by the absorption data for concrete masonry summarized in Figure 4.

Thermal Properties

While a detailed study of the thermal properties of pelletized slag is still in progress, a number of available test results have been summarized in Table 2. Relatively low thermal conductivities are found compared to other lightweight aggregates (0.50 W/m°C for Leca concrete at 1500 kg/m^3 for instance[6]. These low conductivities are probably related to the somewhat vitreous nature of the pelletized slag as the vitreous state has a lower thermal conductivity than the crystalline state[7].

TABLE 2 TYPICAL THERMAL CONDUCTIVITIES OF COMPONENTS INCORPORATING PELLETIZED LIGHTWEIGHT SLAG

Component Measured	Bulk Density kg/m^3	Thermal Conductivity W/m°C
Lightweight Block Face, Canada	1675	0.43
Opilex Block Face, France	1590	0.30
Opilex Block Face, France	1560	0.29
Lightweight Structural, Finland	1900	0.62
Lightweight Structural, Finland	1670	0.44
Loose Pellets, Finland	1185	0.19

PELLETIZED LIGHTWEIGHT SLAG IN CONCRETE MASONRY

The major market for pelletized slag in Southern Ontario is in the production of high pressure, autoclaved (typically 4 hours at 1 MPa, 180°C), lightweight concrete blocks. It should be noted that low pressure curing is more common in other countries, and that pelletized lightweight slag is used very successfully under these conditions (the multi-cell Opilex block produced in France from the Fos pelletized slag (Galex) for instance). The largest application to date was the use of 1¼ million pelletized slag lightweight blocks in the centre core construction and column fire-proofing of the Toronto-Dominion Centre in Toronto. A typical pelletized slag lightweight block mix is given in Table 3, and it should be noted that the cementitious component is 50% Portland cement/50% silica flour in the high pressure autoclaving process. Some features of the use of pelletized lightweight slag in concrete masonry units can be summarized as:

- compressive strengths - an approximately 20% reduction in the cementitious content of the block mixes while maintaining the plant aim compressive strength of 8.3 MPa. (ASTM C90 minimum is 7 MPa).
- production of high strength masonry (net area compressive strength of 21 to 28 MPa) for use in Celdex prestressed integral slabs.
- water absorption - block absorptions are significantly lower than with expanded vesicular slag (Figure 4), and readily meet the ASTM C90 maximum of 29 kg/m^3.
- green strength - improved workability results in less cracking of face shells and webs.
- cementitious properties - the vitrified fines (minus 75 μm) form part of the cementitious component during autoclaving and contribute to the compressive strength.

With the current emphasis on thermal efficiency in building construction, the use of pelletized lightweight slag in the Iseco block developed by CERIB in France should be mentioned[8,9]. A typical Iseco block is made up of three components (multi-cell block, styrofoam insulating insert, and face) and has excellent insulating properties (U of 0.65 W/m^2 °C with a styrofoam insert of 10 cm thickness). It is anticipated that such new developments in masonry will become critical with the trend to lower U values in building codes.

TABLE 3 TYPICAL LIGHTWEIGHT BLOCK MIX INCORPORATING PELLETIZED LIGHTWEIGHT SLAG[a]

Component	Mass, kg	Percent
Silica Flour	40.5	5.7
Portland Cement	40.5	5.7
Fine Pelletized Slag [b]	344.0	48.6
Coarse Pelletized Slag [b]	230.0	32.4
Block Sand	54.0	7.6
	709.0	100.0
Water[c]	28.8	

a. For high pressure autoclaved masonry (~ 4 hours at 1 MPa, 180°C), yields about 50 standard 200 mm blocks.
b. Gradations in Table 1.
c. Plus admixtures.

PELLETIZED LIGHTWEIGHT SLAG IN STRUCTURAL CONCRETE

Pelletized slag use in lightweight structural concrete (cast-in-place or precast), while involving a somewhat higher unit cost than normal weight concrete, can provide a significant overall reduction in construction costs through reduced dead loads and attendant savings in concrete quantities, steel, formwork, foundations, etc. As a number of contributions to Concrete International 1980 cover the economic and design aspects of using lightweight structural concrete, only specific pelletized slag aspects will be discussed here. It should be noted that semi-lightweight (sand-lightweight) structural concrete (bulk density> ASTM C330 maximum of 1840 kg/m^3) is often used rather than fully lightweight structural concrete, as the full weight saving advantages are not enough to warrant the extra cost except in special applications (fire resistance for example). Typical semi-lightweight designs are given in Table 4.

TABLE 4 TYPICAL SAND-PELLETIZED LIGHTWEIGHT SLAG (SEMI-LIGHTWEIGHT) CONCRETE MIX DESIGNS

Compressive Strength	MPa	21	24	27	35
Cement	kg	232	315	345	393
Dry Pellets (-9.5 mm, 855 g/m^3)	kg	500	500	500	495
Dry Natural Sand (1610 kg/m^3)	kg	1015	980	950	920
Total Water	kg	191	190	188	186
Slump	mm	80	90	100	75

NOTES: a. Normal dose of water reducing agent, and air entraining agent for 7± 1% air content, used.
b. Mix designs should be confirmed for specific aggregates and admixtures.
c. Air dry bulk density of 27 MPa mix is typically 1925 kg/m^3.

A number of large applications in the Hamilton area have demonstrated the potential of pelletized slag structural concrete:

1. floors of the 42-story Century 21 building were constructed using pelletized slag, semi-lightweight, structural concrete (24 MPa mix in Table 4). .
2. pelletized slag, fully-lightweight, concrete (~15,000 m3) was used for fire resistance purposes with the cellular steel sub-floors of the McMaster University Medical Centre.
3. floors of an extension to Dofasco's head office used pumped into place, pelletized slag, semi-lightweight, structural concrete.

Pelletized slag structural concrete (fully or semi-lightweight) has excellent workability, pumpability and finishability characteristics. (A pre-soaking of the pelletized slag is recommended for pumping applications.) Standard characterization tests have shown that pelletized slag structural concrete meets all applicable CSA, ASTM, and ACI requirements (drying shrinkage, strength, creep, fire resistance, etc.) as anticipated from many years of expanded (foamed) slag use in concrete[10-12]. It has been found that the pelletized slag's chemistry influences the cement factor somewhat, with more siliceous pellets requiring a higher factor. Mix designs should always be confirmed by the user through actually incorporating the selected fine aggregate and admixtures involved.

OTHER APPLICATIONS FOR PELLETIZED BLAST FURNACE SLAG

While the use of pelletized lightweight slag in structural and masonry concrete has been emphasized, there are several other important current uses, and others are being developed[1,13,14]. In Sweden, pellets are used solely for basement insulation purposes, for instance.

Slag Cement

Pelletized slag is currently being used in slag cement manufacture as it can be produced with a high degree of vitrification for cementitious applications. The largest plant doing this (Standard Slag Cement in Hamilton) produces about 100,000 t/year of separately ground pelletized slag cement meeting CSA Preliminary Standard A363 for Cementitious Hydraulic Slag. Markets for such slag cements are growing rapidly as the substantial energy saving possibilities in comparison to Portland cement manufacture are recognized. The sulfate resistance of pelletized slag cement (cementitious hydraulic slag)/ Portland cement blends is currently being studied at McMaster University. It has, been found that for the slag cement produced in Hamilton, a 50% cementitious hydraulic slag/50% Type 10 Portland cement (normal Portland cement) blend has an equivalent sulfate resistance to Type 50 Portland cement (sulfate resistant cement). Such blends are now being used in concrete applications requiring sulfate resistance.

Partially Ground Pelletized Slag in Block Manufacture

The development of autoclaved blocks incorporating partially ground pelletized lightweight slag as both part of the cementitious component (minus 75 mm material replacing Portland cement), and the fine aggregate component (plus 75 mm replacing block sand), has been completed at McMaster University to the demonstration stage[13,14]. A production schematic of the proposed system is given in Figure 5. The plant trials indicated the technical feasibility of the process with cost savings of 5 to 15% for optimized blends of ground pelletized slag/Portland cement/silica flour. This innovative procedure allows Portland cement replacements of up to about 67% and is suitable for both heavyweight and lightweight autoclaved blocks. Similar procedures have also been developed for autoclaved structural bricks and base stabilization under atmospheric curing[1,13,14].

CONCLUSION

In this brief, descriptive review, it has only been possible to outline the pelletizing process and the use of pelletized lightweight slag in structural and masonry concrete. Hopefully, during Concrete International 1980, other researchers involved with pelletized slag at the developmental research level (BRE, Tarmac and UWIST for instance) will provide further details on the United Kingdom experience with pelletized slag. Given the significant technical, thermal, and economic advantages involved with many lightweight aggregates applications, it is important that designers realize that another aggregate with demonstrated potential - pelletized Slag - is becoming available.

ACKNOWLEDGEMENT

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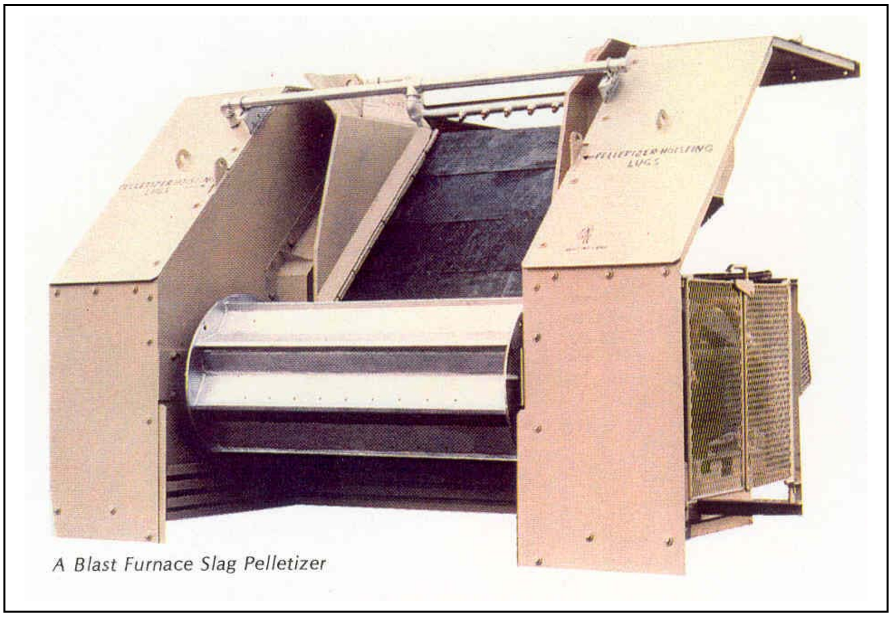
Fig. 1



A Blast Furnace Slag Pelletizer

Fig. 2

Fig. 3 Comparison of Vesicular Expanded and Pelletized Blast Furnace Slag

Fig. 4

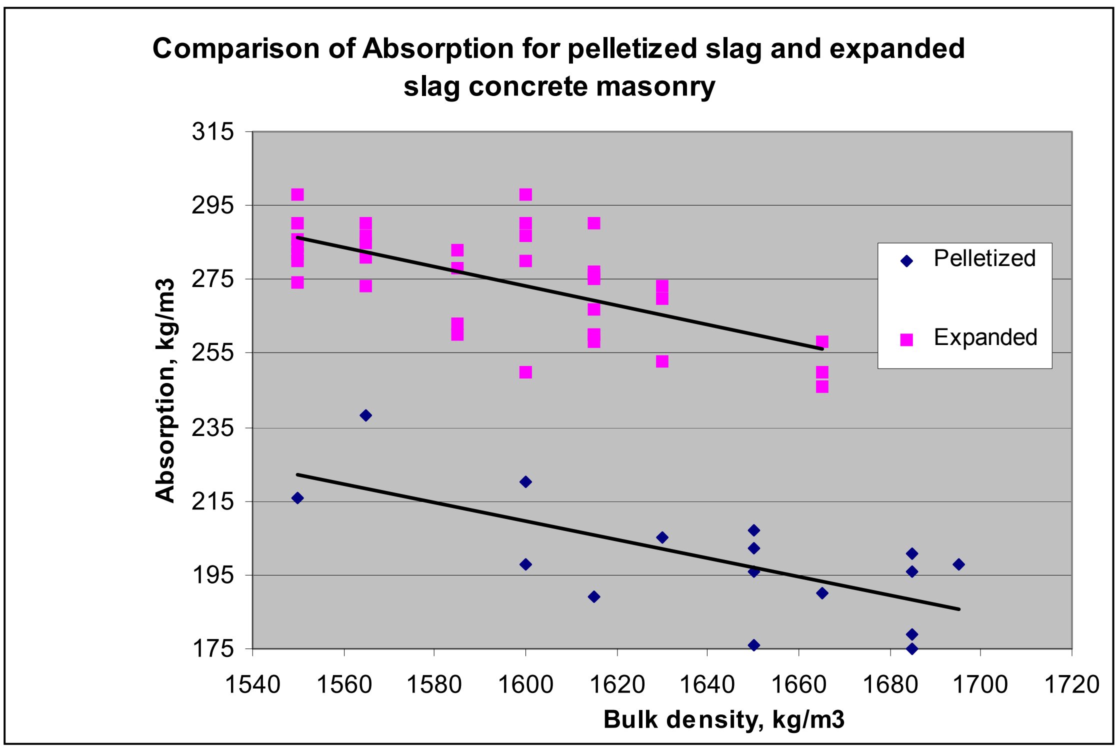


FIGURE 5 PRODUCTION SCHEMATIC FOR USE OF PARTIALLY GROUND PELLETIZED SLAG IN LIGHTWEIGHT AUTOCLAVED BLOCK MANUFACTURE