# USE OF PELLETIZED SLAG IN CONCRETE MASONRY UNITS

R.P. Cotsworth, National Slag LTD Prepared for ASTM Masonry Symposium
Chicago, IL, June 29, 1976

## INTRODUCTION

When iron ore is reduced in a blast furnace, two molten products are formed - hot metal and slag. The volumetric quantity of slag is almost equal to that of iron. There are three common methods of handling the molten slag:

1. air cooling in pits;
2. granulating by immersion in large volumes of water; and,
3. expanding or foaming (as it is known in Europe).

In the basic expanding process, limited quantities of water, steam or air or combinations thereof are injected or otherwise brought into contact with the molten slag to cause the slag to expand. Needless to say, the patent literature is full of methods of doing this and indeed, since 1953 we have utilized five. of these processes ourselves. In the normal process of expanding slag, steam and some gases, particularly hydrogen sulfide are evolved: In 1966 our company was advised by the local Air Pollution Committee that the gaseous emissions from the Stewart process which we were then using were too concentrated and we were requested to change our techniques. After 18 months of continuous experimentation, we developed the slag pelletizer[1] (Fig. 1). The pelletizer is simply a vibrating feeder unit leading to a spinning drum, on the surface of which fins are mounted. Methods of molten flow control and water injection are required. By use of the fins the expanding plastic slag is flung into the air for a distance of approximately 50 feet. [2]

From an air pollution viewpoint, this machine has two advantages. Firstly, while previous processes had been of the batch type this is a continuous process. Gaseous emissions are thereby diluted by generation over a long period of time. More importantly, the mass of pyroplastic foaming slag is dispersed into relatively small individual particles which by immediate contact with air, cool the surfaces sufficiently quickly that further release of gases is terminated. Because of this rapid cooling, it can be thought of as an “air granulator". Tests have shown decreases of $H_2S$ from an initial 4000 ppm utilizing earlier methods to a present 10 ppm average in the stack. [3]

The action of throwing these particles through the air a distance of 50 feet also shapes them in
spheres with each particle having a relatively smooth surface. This was a major Improvement on the rough vesicular product produced by all other methods of

expanding slag. A comparison of the surface characteristics of vesicular and pelletized can be seen in Fig. 2. National Slag Ltd, now has licenses on the process in many countries around the world including the United States, England, France, Finland, Sweden, Japan and Australia.

"While rounded particles, varying in size from 1/2" to 100 mesh are produced, the bulk of the product is in the minus ¼" to plus 16 mesh size ranges. In order to tailor a well graded fine aggregate for lightweight masonry units, which is the major use of this material, it was necessary to take oversize above ¼" and crush it to provide for the deficiencies in size below 16 mesh. Thus even though the average size of the raw product was small, we were obliged to undertake extensive additional crushing to provide adequate gradations. To accomplish this we had in fact to double the H.P. of our secondary crushing unit. Still another plant problem was the containment of the rounded aggregate on the conveyor belts. Clean-up from spillage was a significant problem for a while until we learned how to keep the material on the belt.

# USE IN MASONRY UNITS

PHYSICAL PROPERTIES OF AGGREGATE

For the block industry we produce two gradations - fine and coarse, with size distribution and unit weights as shown in Table 1.

**Table 1** Typical Gradations and Unit Weights of Coarse and Fine Aggregate for Block Masonry

| Sieve Size on Number(U.S.) | Typical Coarse Gradation % Passing | Typical Fine Gradation % Passing |
|---|---|---|
| 5/16 | 100 | |
| 1/4" | 95 | |
| 3/16" | 50 | 100 |
| 8 mesh | 5 | 80 |
| 16 mesh | | 70 |
| 30 mesh | | 50 |
| 50 mesh | | 80 |
| 100 mesh | | 90 |
| Dry Loose Unit Weight lb/ft$^3$ | 52.5 | 67 |

The coarse aggregate is very uniform in size and when in stock has the appearance of a pile of small marbles. Because of the workability imparted to the block concrete the texture of the masonry (which we believe to be the single most important selling feature) is very uniform.

## COMPRESSIVE STRENGTH OF MASONRY

Our previous vesicular expanded slag material required between 250 and 270 kg (550 and 600 lbs.) of cementitious material per 1.4 $m^3$ (50 $ft^3$) batch for masonry units to meet the compressive strength requirements of 7 MPa (1000 psi). When pelletized aggregate first replaced vesicular material, we received reports about the excellent strengths being obtained. In some cases the mix was providing block strengths in excess of 14 MPa (2000 psi). Needless to say, our customers gradually reduced their cementitious contents to provide their plant average strength specification of 8.3 MPa (1200 psi). The typical cementitious content presently used is 250 kg (450 lbs.) per batch. Most of our customers make high pressure cured masonry and replace Portland cement with 50% silica flour.[4] It is theorized that the approximate 20% savings in cementitious materials is due to freedom from loss of cement into the external vesicules combined with a generally better shape to provide maximum strength. Yet another feature of the ability to produce high strength masonry is its use in Celdex® prestressed integral masonry slabs which require units having a net area compressive strength in the range of 21 to 28 MPa (3000 - 4000 psi).

## WATER ABSORPTION

Another physical property of the lightweight masonry which benefited from the change to smooth surfaced pelletized aggregate is the water absorption. ASTM Standard Specification C-90 "Hollow Load Bearing Concrete Masonry Units" presently requires that if the concrete has an oven dry unit weight of less than 1682 kg/$m^3$ (105 lb/$ft^3$) the water absorption shall not exceed 29 kg/$m^3$ (18 lb/$ft^3$). Twenty years ago this requirement was 24 kg/$m^3$ (15 lb/$ft^3$). We found this earlier requirement to be a difficult specification to meet with the vesicular material. The new pellet, however, provides block adsorptions which are consistently less than 20.8 kg/$m^3$ (13 lb/$ft^3$). Continuous compliance with this particular specification requirement is assured. Figure 3 indicates that absorption has decreased an average of almost 4% at any given unit weight of concrete.

## PELLET DENSITIES

An ambiguous characteristic of our pelletized aggregate is its apparently higher unit weight. ASTM Standard Specification C-331 on “Lightweight Aggregates for Concrete Masonry Units" requires that the coarse aggregate has a dry loose unit weight not exceeding 880 kg/$m^3$
(55 lb/ $ft^3$) Pellet aggregate weight is on the order of 840 kg/$m^3$ (52½ lb/ $ft^3$) as compared to 720 kg/$m^3$ (45 lb/ $ft^3$) for vesicular material. It was noted, however, that the dry density of the concrete masonry did not increase significantly with the use of this heavier

material. Again, it was theorized that the pellets provide surface to surface contact rather than point to point contact of the aggregate in the test; i.e. the vesicular material has a higher void content. In order to prove this point, a test sample of pellets of known unit weight was hand crushed, re-screened and retested. The density difference was almost 80 $kg/m^3$ (5 $lb/ft^3$) lower.

## GREEN STRENGTH

A problem which previously bothered us from time to time was cracking of face shells and webs of masonry while being ejected from the block machine. While this is a function of machine type and degree of maintenance it was true that we occasionally had considerable difficulties at some plants. These problems disappeared almost entirely with the advent of pelletizing. The smooth surfaced material provides much improved workability even at the reduced cement contents being used.

## CEMENTITIOUS PROPERTIES

Block manufacturers generally prefer at least 10% passing #100 mesh in their lightweight fine aggregate. We make a special effort to provide this by recycling part of our product to produce extra fines. Our daily sieve analysis on the block fine aggregate product indicates that we meet the 10% objective. A comparison of these analysis and those of our customers, however, have shown that 4-5% of the pass #100 mesh content seems to disappear; i.e. they report only 5-6% through the #100 mesh. After ruling out such plausible conclusions as holes in the testing screens it became apparent that what was actually happening was that the fines in the slag were hydrating and binding together to form larger particles. Some confirmation of this was reported by Emery et al[5]; their Fig. 1 shows that the glass content of the small mesh material is lower than would be anticipated (Fig. 4) because hydration of these fines causes structural changes from glass to crystal.

## FUTURE OUTLOOK

A good potential future market for pelletized slag lies in being able to capitalize on the inherent cementitious hydraulic properties of tile material. It was pointed out earlier that the structure of pelletized slag is primarily a glass. Production techniques are known whereby the product can be made more or less glassy. If glassy pellets are ground to a size finer than 200 mesh and the resulting product is cementitious; i.e. it will hydrate in a similar manner to Portland cement.[7] In some cases activation by lime or Portland cement is helpful. In all cases steam curing, both high and low pressure, helps to overcome initial low early strengths and low rate of hydration.[8]

It is rationalized, therefore, that the use of a glassy pelletized aggregate having a high percentage of fines passing 200 mesh in block manufacture will be partially self-cementing and will help to reduce cement contents. Since the aggregate producer cannot grind and maintain the fines content without drying the material it is further rationalized that the best place to do this is at the block plant. There is absolutely no reason why conventional pellet aggregate as currently supplied cannot be further ground in the moist state at the block plant to produce additional fines passing #200 prior to being fed into the concrete mixer. The relative economics of cost of grinding versus cost of cementitious materials saved are presently unknown. The economics should be good since (a) more fines can be produced by moist grinding than by dry grinding and (b) the high costs of clinker production and drying are saved.

Some work utilizing Portland blast furnace slag cement - Type IS has been done experimentally in concrete masonry in the Hamilton area. The units were high-pressure cured. The regular autoclave cycle and mix proportions were used. The compressive strength results obtained on the units were 5-10% higher than comparable units produced at the same time but which utilized Type I cement. Densities of the slag cement units were slightly higher than those of the regular units. This could indicate that the slag cement was providing additional workability as has been reported elsewhere.

## BRICK TESTS

As a roughly parallel situation to the block proposal just described we conducted some test in a commercial high pressure cured sand-lime brick operation. The first series of results which utilized 10 and 15% pellet fines ground to minus 200 mesh as the only cementitious binder have already been reported.[6] (Table 2)

In the presently described series equal quantities of silica flour were used with the ground slag to determine if this replacement material acts the same way as it does with normal Portland cement. The results are shown in Table 3.

These results indicate the great potential for autoclaved bricks, and blocks utilizing ground pelletized slag as the cementitious binder. When compared with the earlier results[6] they also show that silica flour will react with the slag and contribute to the strength of the masonry.

## CONCLUSION

The use of pelletized slag as an aggregate in lightweight concrete masonry has already provided several advantages to the manufacturer: Among these are better compressive and green strengths as well as easier compliance with absorption requirements. The exploitation of cementitious properties of the aggregate when ground to provide additional percentages of material passing #200 material provide further potential savings to the manufacturer of concrete products. Under high-temperature curing conditions fine siliceous material may be added in large quantities to further enhance the strength.

**Table 2** Initial autoclaved Brick Tests

| Property | Set B1 | Set B2 | Set B3 |
|---|---|---|---|
| Composition, % | | | |
| 4.8 mm (3/16 in) fine pellet slag | 40 | 85 | 90 |
| -75 *μ*m (-#200) ground pellets | 10 | 15 | 10 |
| Fine sand | 25 | -- | -- |
| Coarse sand | 25 | -- | -- |
| Unit Weight | 2016 (126) | 1936 (121) | 1728 (108) |
| Bulk specific gravity | 2.02 | 1.94 | 1.73 |
| Modulus of Rupture | 3650 (530) | 4620 (670) | 1790 (260) |
| Compressive strength, MPa (psi) | 25 (3620) | 35 (5100) | 15 (2330) |
| Absorption, kg/m$^3$ (lb/ ft$^3$) | 214.4 (13.4) | 177.6 (11.1) | 236.8 (14.8) |

Table 3 Autoclaved Brick Tests (a)

| Test No. | | Red Pigmented #4 | Black Pigmented #5 |
|---|---|---|---|
| Composition % | - 3/16" fine pellet slag | 80 | 80 |
| | ground pellets - 200 | 10 | 10 |
| | Silica flour | 10 | 10 |
| Results (b) | Compressive strengths (psi) | 5,950 | 5,300 |
| | Modulus of Rupture (psi) | 1,180 | 798 |
| | Absorption (lb/ft$^3$) | 9.2 | 8.9 |

a) Autoclaving cycle - 3 hours to a pressure of 130 psi
14 1/2 hours holding at 130 psi
2 hours blowdown

b) ASTM Standard specification for Concrete Building Brick (C-55)
Grade U-1 and U-11 - Average Compressive strength 3000 psi minimum
Grade U-1 and U-11 - Absorption 10 lb/ft$^3$ maximum

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Fig. 1 Slag Pelletizer

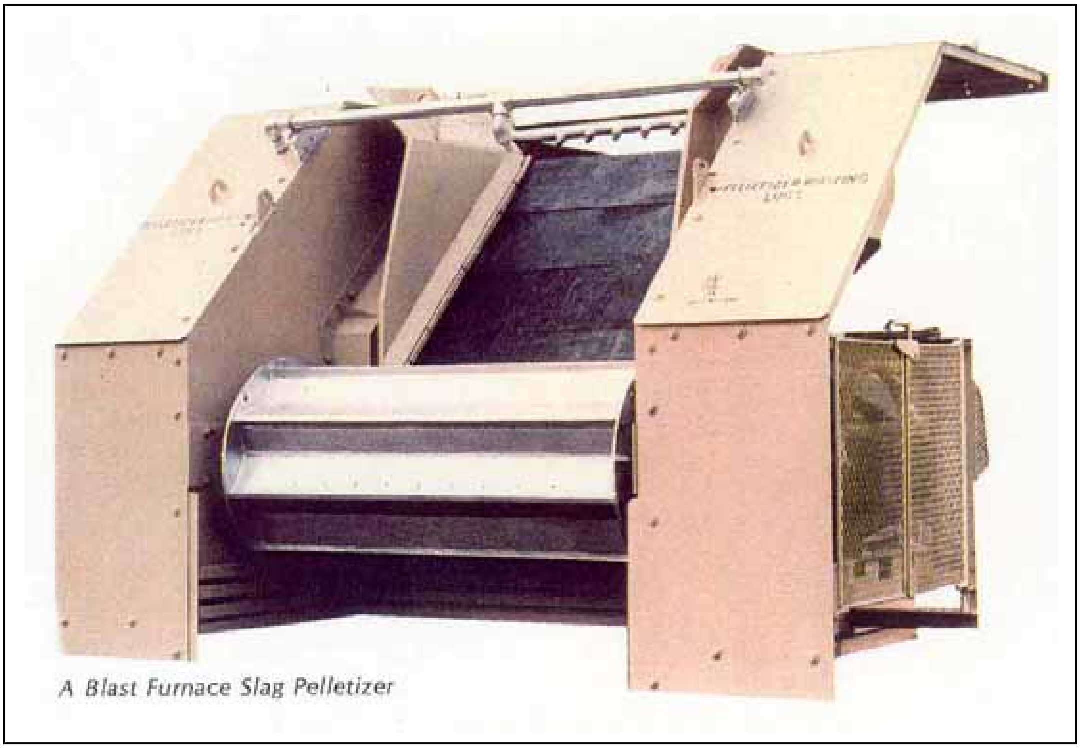


Fig. 2 Visecular Expanded Slag (left) and Pelletized Slag (right)

Fig. 3 Absorption Comparison Between Expanded and Pelletized Masonry

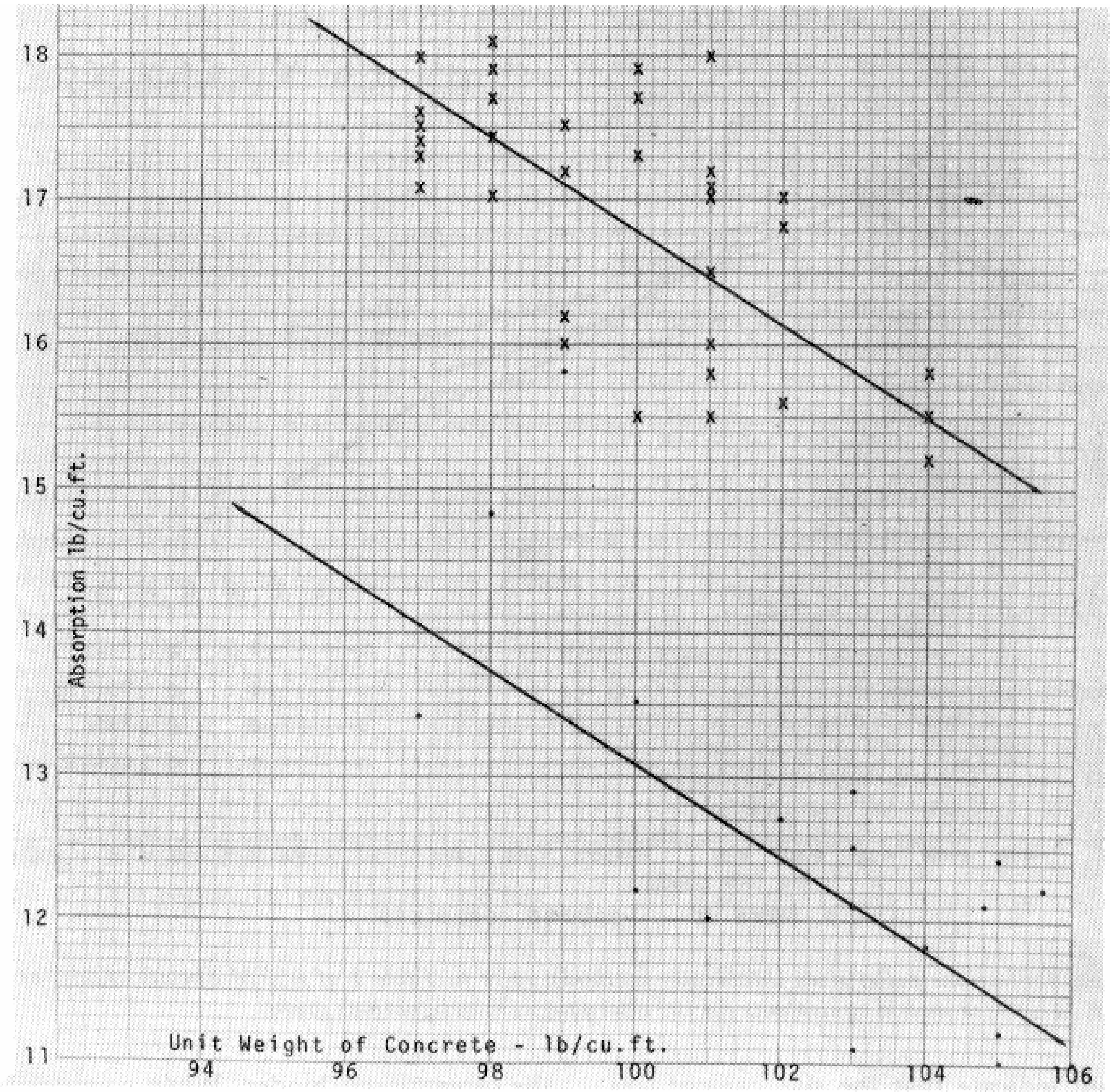

Fig. 4 Glass Content at Different Pellet Size

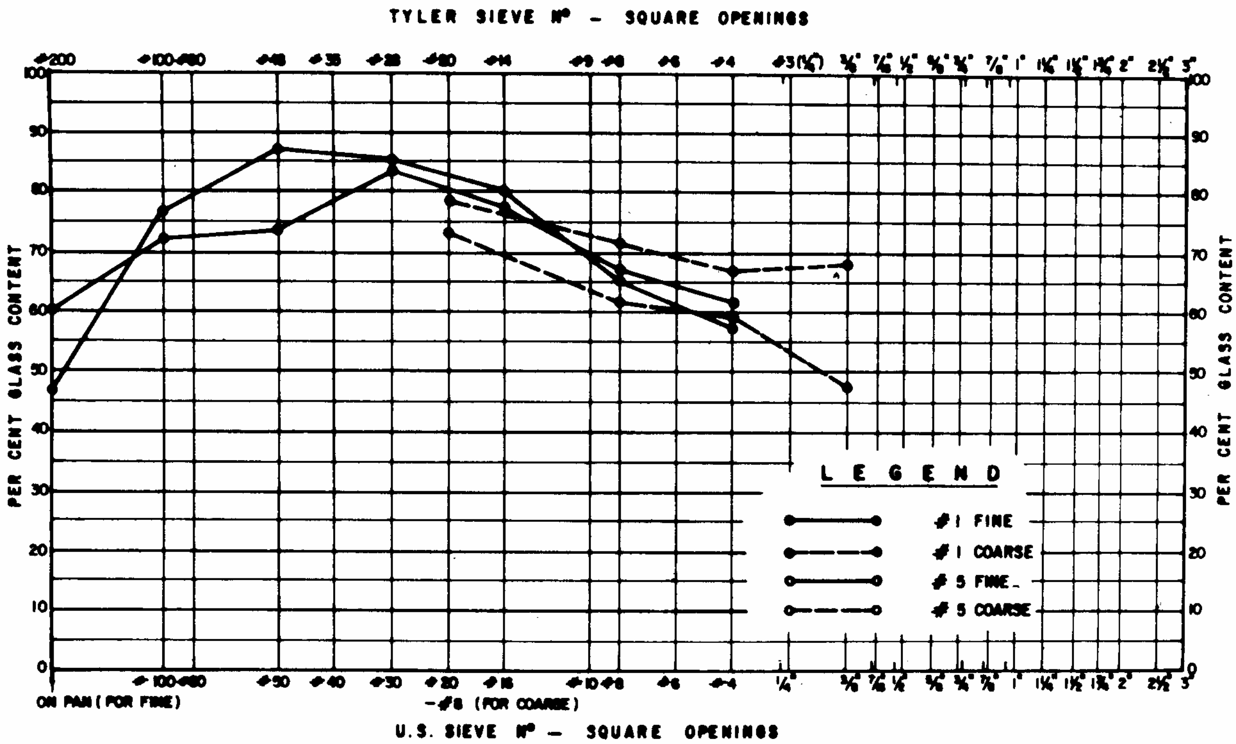


FIG. 4—*Glass content for various pellet sizes (McMaster method); refer to Table 1 of ASTM Specifications for Wire-Cloth Sieves for Testing Purposes (E 11-70) for metric equivalents for the alternate sieve designations given.*