

Course Name: Building Materials as a Cornerstone to Sustainability

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Lecture 01

Furnace

Slag

Hello everyone. So, we have already commenced studying about alternate building materials. The last class we saw fly ash as a building material and how we can utilize fly ash in concrete because there is a lot of production of fly ash and there is a lot of demand for concrete also. Today we will look at another building material which can be made using blast furnace slag. Now, in this lecture we will study the fascinating realm of blast furnace slag which is a material that plays a crucial role in modern construction. We will explore its compositions and a special focus on granulated blast furnace slag, GBFS.

We will understand its unique characteristics. As we journey through this session, we will uncover the numerous advantages it offers in the construction, examining both its structural as well as environmental benefits. However, no material is without its limitations. So, we will also discuss the constraints associated with blast furnace slag.

To bring theory into practice, we will explore real world applications and showcase two exemplary building examples where blast furnace slag has been integral to construction. As we conclude, we will summarize the key takeaways from our exploration. Now, what is blast furnace slag? Blast furnace slag is commonly known as BFS and it plays a crucial role in the iron production process. It is a byproduct from blast furnaces which is used to produce iron. As a by-product of blast furnaces utilized in iron manufacturing, BFS is a non-metallic substance composed of silicates and alumina silicates of calcium and other bases.

So, basically it is a non-metallic product having silicates and alumina silicates of calcium and other bases. The production of BFS occurs simultaneously with the creation of molten iron in the blast furnace. This process involves combining iron ore, coke and limestone in the furnace resulting in the generation of both molten iron and molten slag at an intense temperature of about 1500 degree centigrade. So, it is produced in a molten condition along with iron in a blast furnace. For every ton of hot metal produced approximately 200 to 400 kg of liquid slag is formed.

This molten slag settles at the bottom of the blast furnace creating a layer above the molten iron. Due to its lower density, the molten slag is directed out of the furnace as a liquid with a resemblance to molten lava. So, when iron ore, coke and limestone are placed in a blast furnace, the molten iron and molten slag both are produced at a temperature of 1500 degree Celsius. And around 200 to 400 kg of liquid slag is generated for every ton of hot metal produced. So, the utilization of blast furnace slag in the iron production process highlights its significance as a byproduct with distinctive properties.

Because this less dense molten slag is channeled out of furnace as a liquid and it resembles more like lava because it is so hot by floating on top. So, the slag which comes out; so, the slag which is formed is separately taken out and the molten iron is separately taken out because of the difference in density. Let us look at the composition now. So, in understanding blast furnace slag, its composition becomes very important.

The main components of slag from blast furnace include silicon dioxide approximately 27 to 38 percent, aluminum oxide which is about 7 to 15 percent and calcium oxide which is 34 to 43 percent. Notably, the raising of slag is associated with an increase in its calcium oxide content. Basically, a term denoting the ratio of calcium oxide to silicon dioxide plays a crucial role in influencing compressive strength. An interesting observation is that improvements in compressive strength continue up to 10% and 14% for magnesium oxide and aluminium oxide respectively. Beyond these percentages, no additional enhancements are achievable.

To understand the relationship between slag composition and hydraulic activity, various compositional ratios often referred to as hydraulic indices have been established. These indices are frequently reported as the binder compressive strength providing valuable insights into the performance and properties of blast furnace slag in different applications. If we look at ground granulated blast furnace slag, in its production the cooling of molten slag is a crucial step. The high pressure water jets are employed to rapidly cool the molten slag causing it to transform into granular particles smaller than 5 millimetres. These large particles can thus serve as aggregates in various construction applications.

The swift cooling process prevents the formation of larger crystals resulting in approximately 95% of the granular material to be composed of non-crystalline calcium alumino silicates. The granulated slag undergoes further processing including drying, grinding and treatment in a revolving ball mill. The end product is ground granulated blast furnace slag. It is an extremely fine powder with enhanced properties. Remarkably, it can substitute regular cement on a weight for weight basis with replacement rates ranging from 30% to 85%.

This versatile material finds application in sustainable construction practices and contributes to the reduction of environmental impact in the building industry. When it comes to the physical properties, ground granulate blast furnace slag possesses distinctive physical properties. It is characterized by a glassy material displaying color variations from beige to dark to off-white. When finely ground, this slag takes on a typically white color contributing to a lighter and brighter appearance in concrete applications. Despite having a specific gravity less than that of cement, ground granulated blast furnace slag exhibits higher fineness enhancing its suitability for various construction purposes.

Its particle morphology is noteworthy. The diameter of ground granulated blast furnace slag varies within the range of 9 to 13.69 nanometer with corresponding surface areas spanning from 510 to 685 meter square per kg. The processing method significantly influences particle shape with vibromil processing resulting in predominantly spherical particles. On the other hand, ball mill processing produces particles with anomalous shapes characterized by clear edges.

The choice of grinding techniques impacts the overall appearance and surface characteristics of this slag, underlining the importance of understanding and optimizing these parameters in construction applications. The percentage of ground granulated blast slag in various cement blocks as an alternate to cement depends and it results in various strength as well as aesthetics of the block. Ground granulated blast furnace slag also exhibits significant chemical properties that define its suitability for construction applications. With the glass content ranging from 85 to 90 percent, ground granulated blast slag possesses inherent cementitious properties which is crucial for enhancing the performance of concrete. Since the primary chemical constituents are oxides of calcium, silicon, aluminum and magnesium, these distinguish ground granulated blast slag from ordinary Portland cement influencing its reactivity and functionality.

The assessment of the slags reactivity adheres to ASTM C 989 standards considering factors such as chemical composition, alkali concentration, glass content and fineness. The hydraulic activity index, which is determined by the ratio of the oxides of calcium, magnesium, aluminum and silicon, provides insights into the slag's reactivity. This slag undergoes a complex hydration mechanism when combined with Portland cement activated by alkalis and sulfates. So, understanding these chemical properties, reactivity factors and the hydration reaction is very important and pivotal for leveraging the advantages characteristics of ground granulated blast furnace slag. Let us now look at the advantages of this material.

The utilization of ground granulated blast furnace slag in cement and concrete offers a

multitude of benefits. This includes improvement in workability and compaction along with increased pumpability, increased strength, it leads to enhanced durability, and it gives reduced permeability. Thus, ground granulated blast furnace slag contributes to enhance strength, durability and reduce permeability of concrete structures making them more resilient over time. Its high resistance to chloride penetration, sulphate attack and alkali silica reactivity ensures durability in diverse environmental conditions. Additionally, this slag results in certain more advantages which is low heat of hydration.

The improved surface finish and enhanced architectural appearance is an added benefit especially for architects where aesthetics becomes a very important aspect in the design. Its application suppresses efflorescence and extends the life cycle of concrete structures, ultimately reducing maintenance and repair costs. The incorporation of ground granulated blast slag not only slashes lifetime construction costs but also aligns with environmental goals as its production involves virtually zero carbon dioxide emissions along with no emissions of any of its other oxides. Let us now look at one of the most important aspect of any of the building materials that we are studying and that are its environmental benefits. Incorporating ground granulated blast furnace slag in concrete not only enhances its performance but also brings significant environmental benefits.

One notable advantage is the reduction in carbon dioxide emissions as ground granulated blast furnace slag serves as a sustainable substitute for Portland cement. Additionally, GGBFS or ground granulated blast furnace slag exhibits lower embodied energy during production compared to traditional cement, contributing to overall environmental sustainability. The resource efficiency of this material is evident in its ability to reduce the amount of cement required in concrete mixtures, promoting responsible use of materials. As a byproduct of steelmaking, this material aligns with waste reduction goals by repurposing industrial waste for construction purposes. Moreover, studies indicate that ground granulated blast furnace slag can safely immobilize toxic metals in concrete.

Now, if we look at the benefits of using ground granulated blast furnace slag, we can see that as compared to normal concrete. There is a 30% decrease in temperature that is required, there is a reduction of 7.5% in terms of cost and most important is 30% reduction in carbon dioxide emissions. Thus, using this ground granulated blast furnace slag in concrete, gives us a very high returns in terms of environmental benefits. Of course, it comes with a limitation. So, when considering ground granulated blast furnace lag for construction, it is important to note a few aspects.

Firstly, there might be a higher initial cost compared to conventional cement. Additionally, due to its lower early strength, it is not suitable for reinforced cement concrete work impacting certain construction applications. Lengthy initial setting period

makes it less ideal for emergency repairs. Achieving colour consistency in ground granulated blast furnace slag can be challenging because this will influence the aesthetic preferences. It is crucial to ensure compliance with local building codes as ground granulated blast furnace slag may not align with regulations in all regions.

Lastly, assessing quality can be nuanced as it depends on various factors, making it somewhat challenging to easily differentiate. Understanding these considerations allows for informed decisions when incorporating ground granulated blast furnace slag in construction projects. Let us now look at the applications of ground granulated blast furnace slag. It is a valuable component in the construction industry often used in combination with regular Portland cement and or other pozzolanic ingredients to create robust and long lasting concrete structures. This combination is employed both, in ready mixed and site patched concrete contributing to the durability of the final product.

Ground granulated blast furnace slag plays a crucial role in the manufacturing of slag cement with enhanced quality. In manufacturing settings, concrete with GGBS cement gains strength gradually over an extended period and sets more slowly compared to concrete made solely with regular Portland cement. Its applications are diverse, extending to concrete roads, flyovers, dams, effluent treatment plants, marine work, pile foundation work, water retaining structures, commercial and residential construction, pre-cast concrete construction, soil stabilization and various other construction projects. So, we can apply ground granulated blast furnace slag in concrete roads, flyovers, dams, effluent treatment plants, marine works, piles, pile foundations, water retaining structures and building construction. We can also use these in precast concrete for soil stabilization.

That said, we can see that it has extremely wide range of applications and it is up to us to make use of its application in architecture. Let us now look at case studies. Here we look at a case study called Cast House. The Bureau de Change Architects designed office space spans about 420 square meters in London stands and it is a testament to a harmonious blend of architectural homage and environmental consciousness. The architects sought to emulate the enduring craftsmanship and superior quality of the 1930s houses, preserving a timeless aesthetic while prioritizing sustainability.

The precast panels used in construction bear a high concentration of ground granulated blast furnace slag, a cement substitute that not only imparts a distinctive whitewash feel to the concrete but also actively reduces embodied carbon dioxide, showcasing a commitment to eco-friendly design. To enhance the concrete's texture, additional moulds at the rear imprinted with brick patterns were ingeniously incorporated creating a softer and more varied visual impact. This project not only reflects a thoughtful design

philosophy but also serves as a noteworthy example. Of how architectural aesthetics and environmental responsibility can seamlessly coexist in contemporary urban development, particularly in the bustling cityscape of London. The next building example we will see is the **Meta** headquarters.

So, Bennett's associates' innovative design for an expansive office building in London covers nearly 48,973 m². It exemplifies a commitment to sustainability from the project's inception itself. With a focus on reducing the use of first-life materials and minimizing embodied carbon, the architects incorporated recycled aluminum for the facade contributing to resource efficiency and eco-friendly construction. Ground granulated blast furnace slag is a byproduct of the steel industry and it plays a significant role in the project by replacing conventional cement in large portions of the concrete. This sustainable choice not only repurposes industrial waste but also substantially diminishes the carbon footprint associated with concrete production.

This efficient design has resulted in a noteworthy saving of 10,564 tons of carbon dioxide equivalent, making it an extremely environment friendly and a green building. So, let us summarize. Ground granulated blast furnace slag is a glassy byproduct which is rich in calcium, silicon, aluminum and magnesium oxides and it stands as a versatile asset in construction. Its incorporation into concrete brings a myriad of benefits enhancing workability, strength and durability while simultaneously reducing permeability and maintenance cost. Ground granulated blast furnace slag goes beyond structural advantages embodying environmental sustainability.

By lowering carbon emissions, minimizing embodied energy and repurposing industrial waste, ground granulated blast furnace slag aligns with sustainable construction practices. This versatility extends to various construction projects from roads to dams. Notably in architectural design, this is exemplified by the London residential project from Bureau de Change Architects and ground granulated blast slag plays a pivotal role. Here it not only emulates the craftsmanship of the past, but also contributes to an aesthetically appealing design while promoting environmental responsibility. Having seen what is ground granulated blast furnace slag, its properties which matches or aligns with concrete along with its physical and chemical composition, its advantages and limitations, we have also seen its applicability in architecture.

Having seen that, we have also seen two case studies which were built using ground granulated blast furnace slag as their building material and therefore, we have no other excuse to not incorporate these into buildings. Otherwise, we will keep on using humongous amount of cement in our concrete and only end up making the planet warmer. In order to make the planet greener we need to incorporate these alternate

building materials in our designs. With this I will stop today's class and we will continue with another alternate building material in our next class. Thank you.