POZZOLANS
(Supplementary Cementitious Materials)

Pozzolan

- The name Pozzolan comes from the town Pozzuoli, Italy.
- Ancient Romans (~100 B.C.) produced a hydraulic binder by mixing hydrated lime with soil (predominantly volcanic ash)
- Horasan mortar, mixing lime with finely divided burned clay, is extensively used by Ottomans
- Nowadays, the word pozzolan covers a broad range of natural and artificial materials.

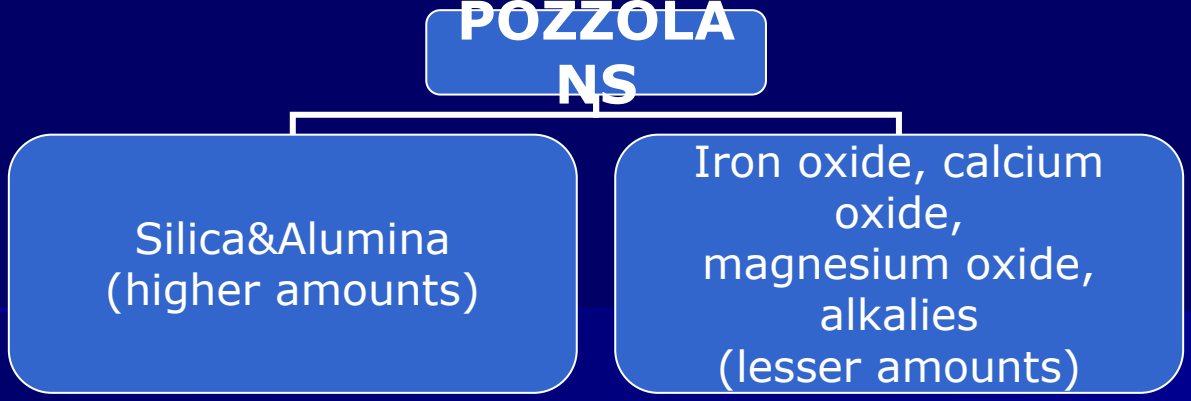
Pozzolan

a material that, when used in conjunction with portland cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both.

- Natural (Volcanic ash, volcanic tuff, pumicite)
- Artificial (fly ash, silica-fume, granulated blast furnace slag)

Pozzolan

- Siliceous or aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in **the presence of moisture**, chemically react with calcium hydroxide $Ca(OH)_2$ to form compounds possessing hydraulic cementitious properties.



POZZOLANIC REACTIONS

Calcium Hydroxide+Silica+Water → "Calcium-Silicate-Hydrate"

(C-S-H)

C-S-H provides the hydraulic binding property of the material.

Pozzolanic Activity: Capacity of pozzolan to form alumino-silicates with lime to form cementitious products. (How good how effective the pozzolan is!)

FACTORS THAT AFFECT THE ACTIVITY OF POZZOLANS

1) SiO_2 + Al_2O_3 + Fe_2O_3 content

2) The degree of amourpheness of its structure

3) Fineness of its particles

1) $SiO_2 + Al_2O_3 + Fe_2O_3$

- The greater amount of these, the greater its activity.
- ASTM C 618 & TS 25 → min "$SiO_2+Al_2O_3+Fe_2O_3$" for natural pozzolans > 70%
- Fly Ash - ASTM

✔ Class C→ from lignitide or subbituminous coals ($SiO_2+Al_2O_3+Fe_2O_3$>50%)

✔ Class F→ from bituminous coals and $SiO_2+Al_2O_3+Fe_2O_3$>70%

- Silica fume → SiO_2 ≈ 85-98%
- Blast Furnace Slag→ SiO_2 ~ 30-40%
  Al_2O_3 ~ 7-19%
  CaO ~ 30-50%

2) Amorphousness

- For chemical reaction → pozzolans must be amorphous
- Volcanic ash, volcanic tuff, fly ash, silica fume are all amorphous by nature.
- Clays → contain high amounts of silica & alumina but have a crystallic structure! (Do not possess pozzolanic activity)
  - However, by heat treatment, such as calcining ~700-900°C crystallic structure is destroyed & a quasi-amorphous structure is obtained.

2) Amorphousness

- Clay → does not possess pozzolanic property
- Burned clay → possess pozzolanic property

- Blast furnace slag → contain high amounts of silica, alumina & lime.
  - However, if molten slag is allowed to cool in air, it gains a crystal structure. * do not possess pozzolanic property.
  - However, if it is cooled very rapidly by pouring it into water, it becomes a granular material & gains amorpousness. * possess pozzolanic property.

3) Fineness

- Pozzolanic activity increases as fineness increases.
- Volcanic ash, rice husk ash, fly ash, condensed silica fume are obtained in finely divided form.
- Volcanic tuff, granulated blast furnace slag & burned clay must be ground.

DETERMINATION OF POZZOLANIC ACTIVITY

- Pozzolanic activity is determined by "strength activity indexes"

- Six mortar cubes are prepared (ASTM)

→"Control Mixture" 500 g portland cement+1375 g sand+242 ml water

→"Test Mixture" 400g of portland cement+100g of pozzolan+1375g of sand+some water for the same consistency

- Compressive testing at 7 or 28 days
- Strength Activity Index (SAI) =A/B*100
- A=f'_c of test mixture
- B=f'_c of control mixture
- ASTM C 618 $\rightarrow$ SAI $\geq$ 75%

CHEMICAL COMPOSITION OF POZZOLANS

- Silica Fume is mostly SiO_2
- G. G. Blast Furnace Slag→ high amounts of CaO (self-cementitious)
- Class C Fly Ash has CaO (self-cementitious)

Chemical Analysis of Typical Fly Ash, Slag, Silica Fume, Calcined Clay, Calcined Shale, and Metakaolin

	Artificial Pozzolans				Natural Pozzolans		
	Class F fly ash	Class C fly ash	Groundslag	Silica fume	Calcined clay	Calcined shale	Meta-kaolin
SiO_2, %	**52**	**35**	35	**90**	58	50	**53**
Al_2O_3, %	**23**	**18**	12	0.4	29	20	**43**
Fe_2O_3, %	**11**	**6**	1	0.4	4	8	0.5
CaO, %	5	**21**	**40**	1.6	1	8	0.1
SO_3, %	0.8	4.1	9	0.4	0.5	0.4	0.1
Na_2O, %	1.0	5.8	0.3	0.5	0.2	—	0.05
K_2O, %	2.0	0.7	0.4	2.2	2	—	0.4
Total Na eq. alk, %	2.2	6.3	0.6	1.9	1.5	—	0.3

SILICA FUME

FLY ASH

GRANULATED BLAST FURNACE SLAG

Selected Properties of Typical Fly Ash, Slag, Silica Fume, Calcined Clay, Calcined Shale, and Metakaolin

	Class F fly ash	Class C fly ash	Groun dslag	Silica fume	Calcined clay	Calcined shale	Meta-kaolin
Loss on ignition, %	2.8	0.5	1.0	3.0	1.5	3.0	0.7
Blaine fineness, m^2/kg	420	420	400	**20,000**	990	730	**19,000**
Relative density	2.38	2.65	2.94	2.40	2.50	2.63	2.50

Typical Amounts of Pozzolans in Concrete by Mass of Cementing Materials

- Fly ash
  - Class C 15% to 40%
  - Class F 15% to 20%
- Slag 30% to 45%
- Silica fume 5% to 10%
- Calcined clay 15% to 35%
  - Metakaolin 10%
- Calcined shale 15% to 35%

REQUIREMENTS FOR AN ACCEPTABLE QUALITY OF POZZOLAN

- TS 25 → Natural Pozzolans
- TS 639 → Fly Ash
- ASTM C 618 → For Natural Pozzolan & Fly Ash

	Natural	Class F	Class C
Fineness (max. % retained when wet sieved on 45 μm sieve)	34%	34%	34%
Strength Activity Index	75	75	75
min "SiO2+Al2O3+Fe2O3"	70	70	50

USES OF POZZOLANS

1) Direct use of Pozzolan by Mixing it with Calcium Hydroxide

   Extensively used in ancient times but not very common now.

2) Use of Pozzolan in Producing Blended Cements

   Grinding "Clinker+Pozzolan+Gypsum"→ Portland Pozzolan Cements Extensively used

3) Use of Pozzolan as an Admixture

   "Cement+Pozzolan+Aggregate+Water"→ Concrete