USE OF WASTE FLY ASH FROM POWER PLANTS IN CEMENTITIOUS COMPOSITES FOR STRUCTURAL ELEMENTS

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Concrete production

Global Use: 12 billion tons (per year)

In 1913, the first load of pre-mixed concrete was produced

The capability to order concrete already mixed at another facility made huge changes in the construction industry.

Concrete: 2nd biggest world consumption after water

Engineers of R/concrete could not foresee the problems created by its wide range use to the future generations and the planet

Concrete environmental cost

Capitalistic model – Linear flow of production

Harvesting of natural resources → **creation and use of synthetic products** → **disposal in landfills**

lime and **clay** for the production of cement, coarse aggregates are produced from **crashed stones**, **sand**, steel as an alloy of **iron** and **carbon**, **water**

environmental effects (carbonation), natural phenomena (earthquakes), climate conditions (rain, snow, wind, sea cost chlorides)
service life of 50 years.

construction waste, contain lead, asbestos or other hazardous substances

production of Portland cement

- 5% of global CO_2 emissions
- Cement production is expected to rise from 2.55 billion tons in 2006 to 3.7-4.4 billion tons by 2050
- equivalent amount of CO_2 emitted to the environment

- **1987 UN** definition, "**sustainable development**" is "meeting the present needs without compromising the ability of future generations to meet their needs".

Sustainable structural design – holistic approach

reduce **CO_2 emissions**, reduce the use of **natural resources** and increase the use of **waste/byproducts**

One of the most promising attempts for sustainable development for concrete is the use of fly ash (FA), a byproduct of the energy industry that otherwise ends up in wastelands creating lots of environmental problems

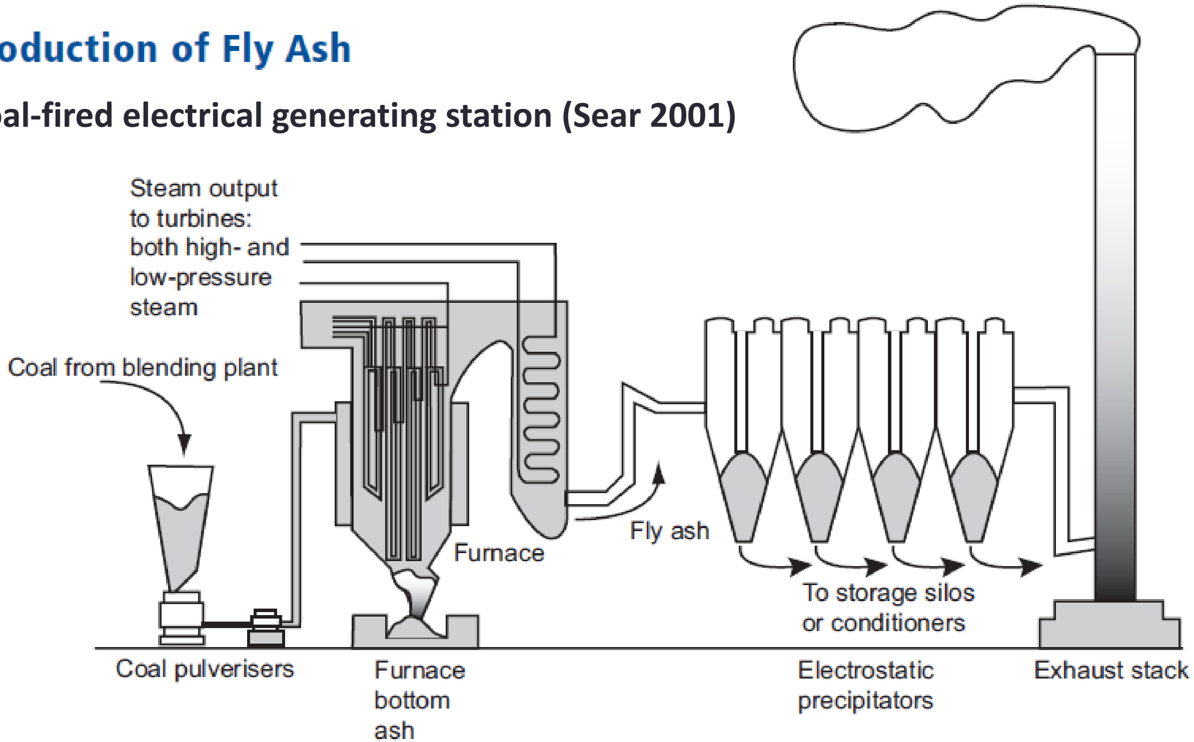
Increase the life time of structures – **use of fibers**

aged structures 70% of the built environment in the developed countries:
end of their service life, or accumulated extensive damage, or no longer meet the Modern Codes' provisions for earthquake resistance or durability
great expenditure for rehabilitation and maintenance.
50% of the total expenditure for construction is needed for maintenance and repair in many industrial countries

Origin of Fly Ash

Production of Fly Ash

coal-fired electrical generating station (Sear 2001)



substantial amounts of **silicon dioxide (SiO_2)** (both amorphous and crystalline), **aluminum oxide (Al_2O_3)** and **calcium oxide (CaO)**, the main mineral compounds in coal-bearing rock strata

Coal is first pulverized in grinding mills before being blown with air into the burning zone of the boiler. In this zone the coal combusts producing heat with tempertures reaching approximately 1500°C (2700°F). At this temperature the non-combustible inorganic minerals (such as quartz, calcite, gypsum, pyrite, feldspar and clay minerals) melt in the furnace and fuse together as tiny molten droplets. These droplets are carried from the combustion chamber of a furnace by exhaust or flue gases. Once free of the burning zone, the droplets cool to form spherical glassy particles called fly ash. The fly ash is collected from the exhaust gases by mechanical and electrostatic precipitators.

- **ALSO CONTAINS**: arsenic, beryllium, boron, cadmium, chromium, hexavalent chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with very small concentrations of dioxins and PAH compounds [10], [11].

Dec. 22, 2008, a containment dike ruptured Kingston Fossil Plant, Tenn.
4.2 billion L of coal fly ash slurry over 122 hectares of surrounding land, damaging homes and flowing into nearby rivers. This spill was the largest fly ash release in U.S. history. Cleanup costs were estimated between $525 - $825 million, not including potential long-term cleanup [12].

major need in **recycling** of the total amount of fly ash produced for a series of reasons such as **contamination** of the **air**, use and contamination of **landfills**, dangers of **spilling** and **contamination** of **water basins**, risks not only for human but also for the environment

Fly Ash

Advantages:

-cost decrease
-decrease of heat of hydration
-increase of workability
-decrease of water
-increase of strength
-denser microstructure
-increase of durability
-control of alcali-silica reaction
-up to 70% of cement replacement have been successfully developed
-ACI has recently issued Code provisions for HVFA concrete

hydraulic or pozzolanic activity -
As per ASTM:
Limiting the use as a cement replacement
20-35% class C
15-25% class F

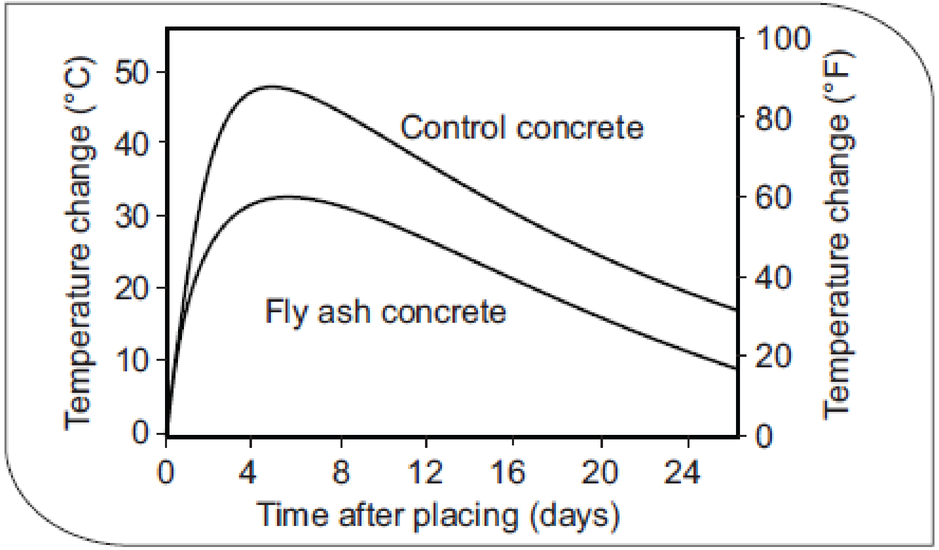
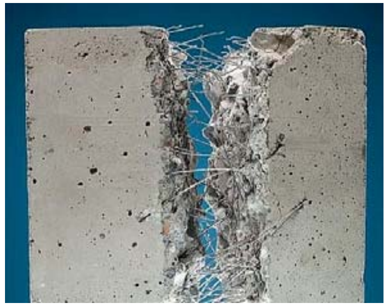


Figure 10. Effect of fly ash on temperature rise in concrete dams (Mustard 1959).

CONCRETE FAILURE-CRACKING

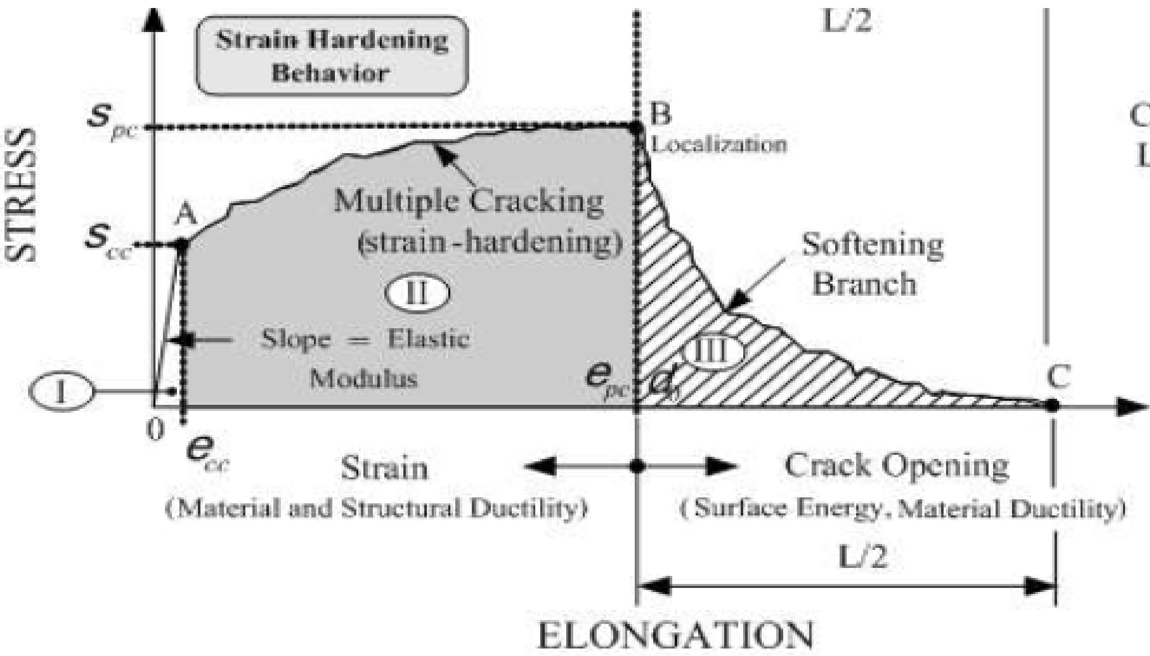
Tensile strength of concrete**-2MPa-considered Ø for flexural design**

Tensile strain **- brittle - 0.15‰**



NEW TYPE OF CEMENT COMPOSITES WITH STRAIN HARDENING PROPERTIES IN TENSION

PVA fibers->
Strain Hardening
(multiple cracking with increase of tensile stress capacity, small crack widths, small distance between cracks), increased energy consumption



Typical stress-elongation curves in tension of fiber reinforced cement composites (A. Naaman, 2007)

SHCC mix design

Mix	Cement	Fly Ash	Sand (<300μm)	Water	HRWR	Fibers
HVFA-control	1	1.2	0.8	0.56	0.012	-
M45					0.024	**2 % Vol.**

- Eurocrete Fly-Ash Type F (ASTM C-618, EN202)
- Extremely fine 0.45μm
- Increased sustainability (**60%** of cement to **FLY ASH)**
- No **coarse aggregates** are used
- Addition of fibers increases capacity for energy release consumption
- Can withstand great tensile and shear deformations
- Same or greater compressive strength and durability in regards to normal concrete
- **Self-compacting** (reduction of placement energy and easier in reinforcement conjunction regions)

PVA fibers

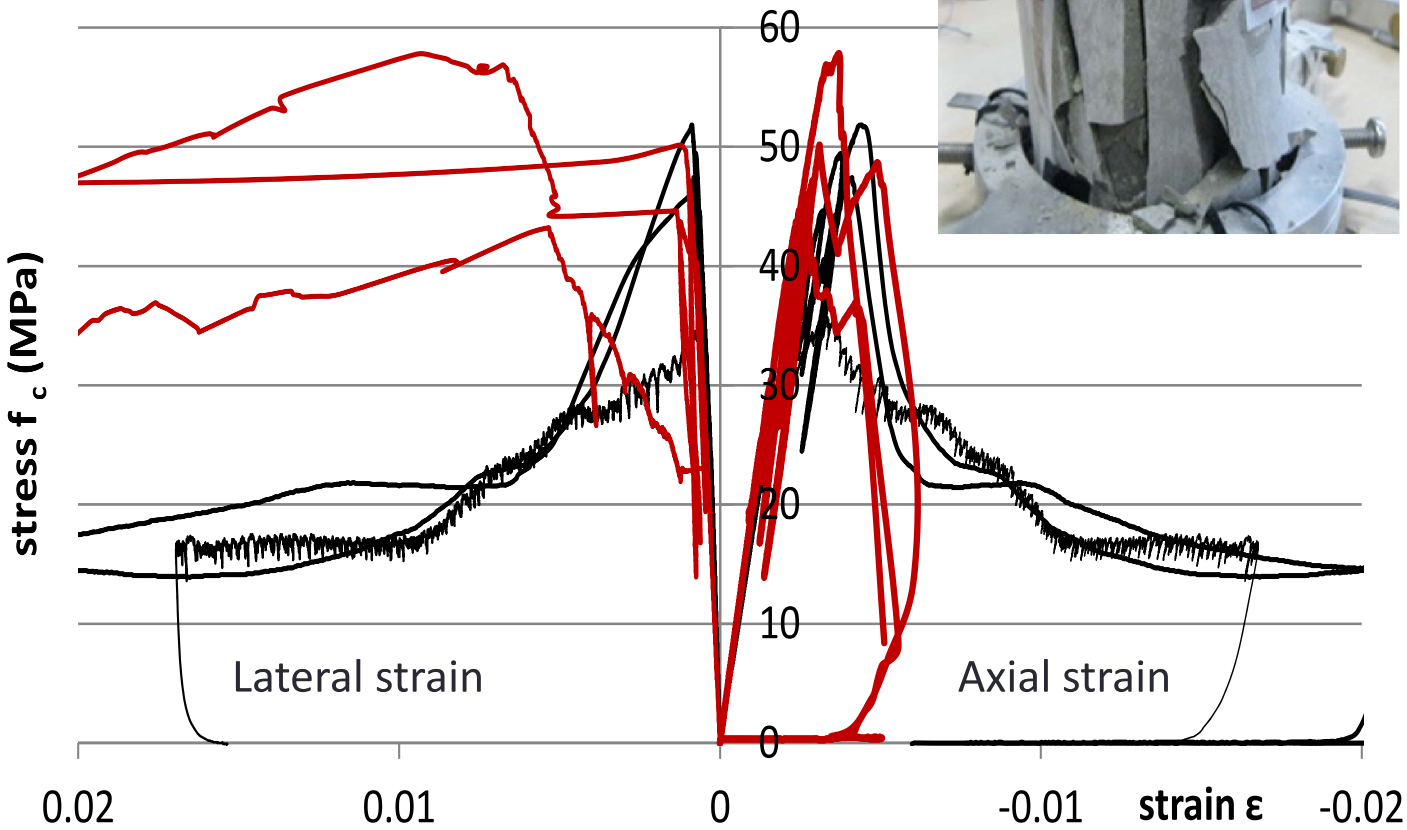
12mm long

- 39μm diameter
- tensile strength = 1600MPa
- E = 40 GPa
- ρ = 1300 kg/m3
- HYDROPHILIC

Uniaxial Compression

concrete cylinders (≈100x200mm)
load applied at constant rate of 1.5µm/s.

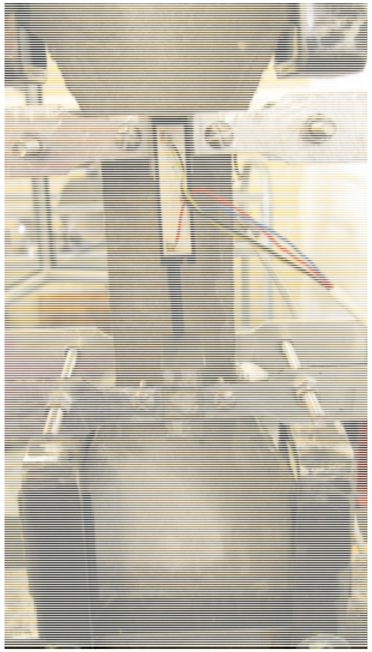
matrix without fibers
collapse by the excessive lateral expansion

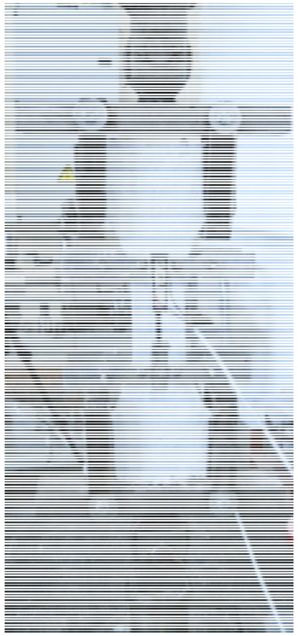


Uniaxial compression stress-strain

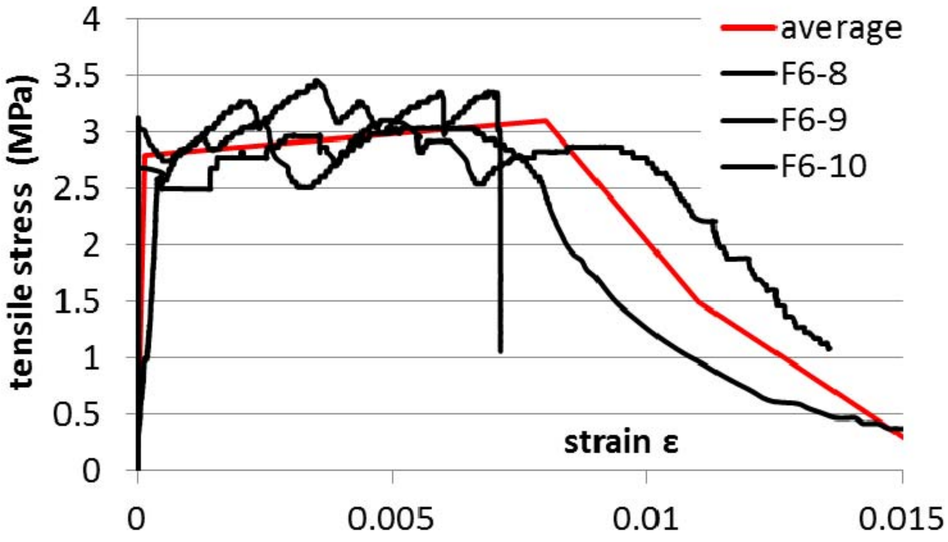
Direct Tension

direct tensile dog-bone specimens
-special mounting equipment
-difficult to conduct
-lack of any tolerance to imperfection in alignment and placement
-spurious localized fracture instead of ductile response is often witnessed.

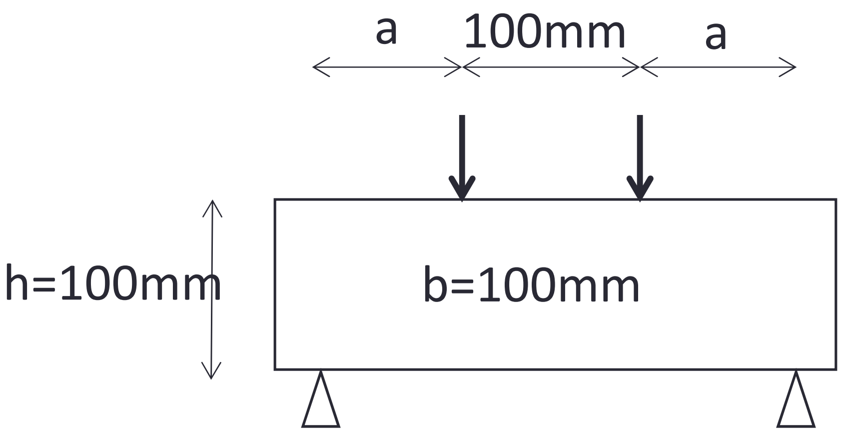


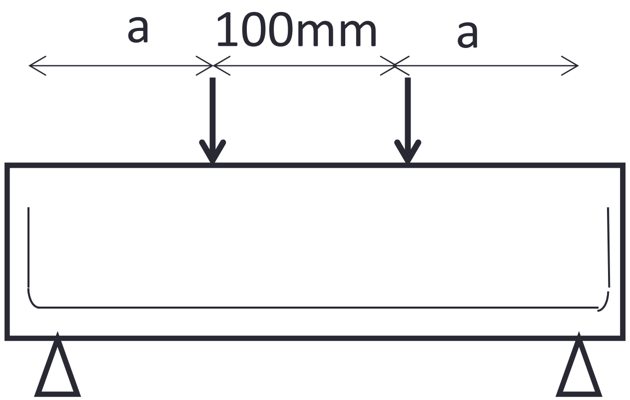


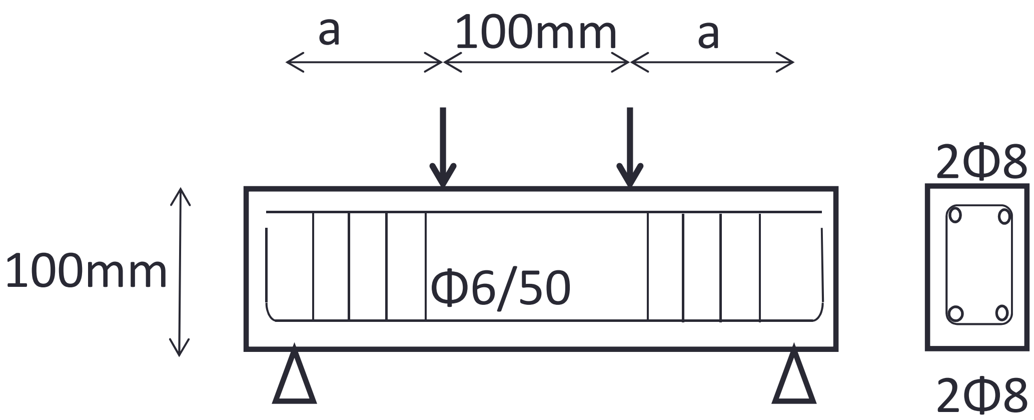
Displacement control 0,0025mm/s
Measuring length 100mm
Critical cross section 25x50mm

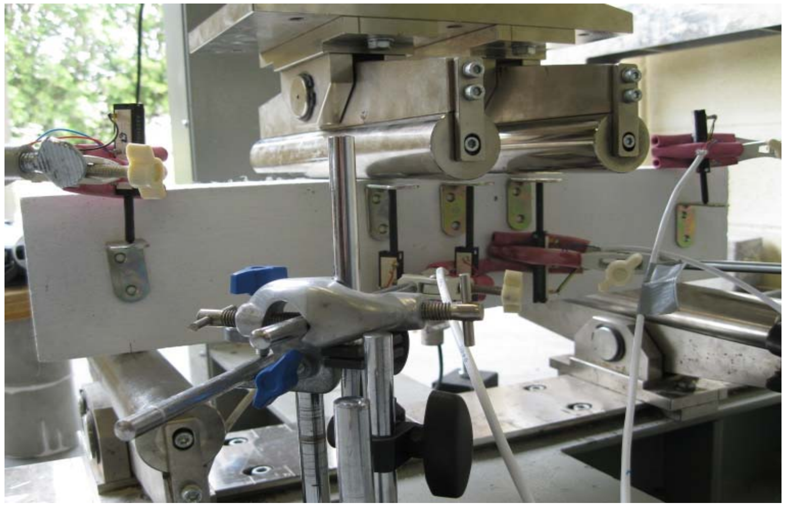


Four Point Bending Tests





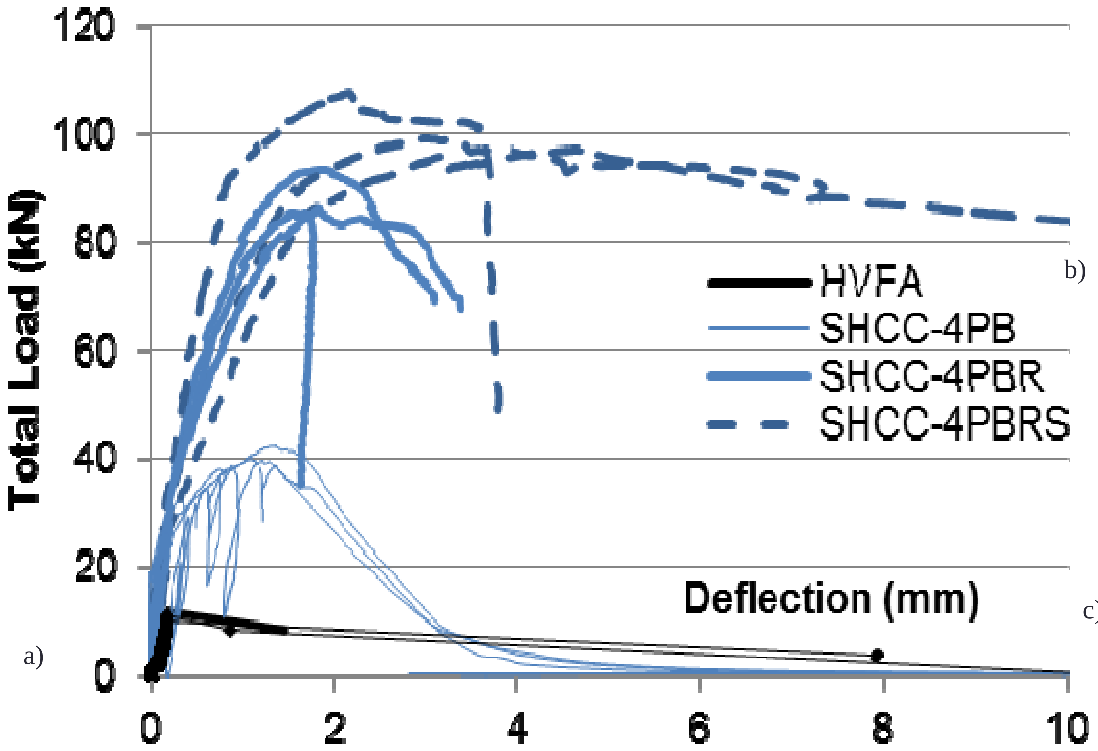




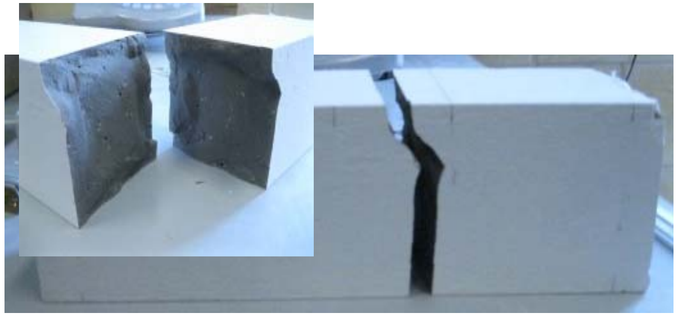
R/SHCC
2Φ8
b=100mm, d=80mm

M=10kNm

R/C
2Φ8
b=200mm, d=240mm

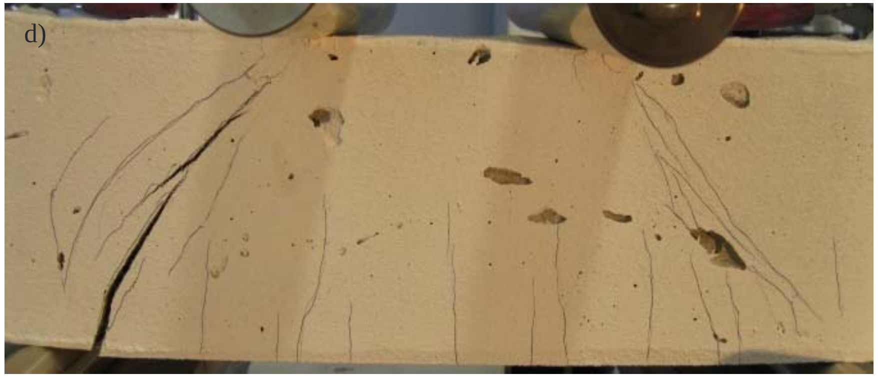


a)

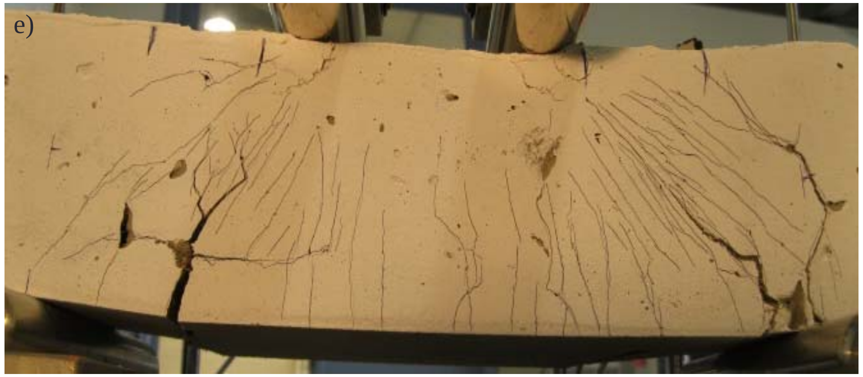


b)

c)



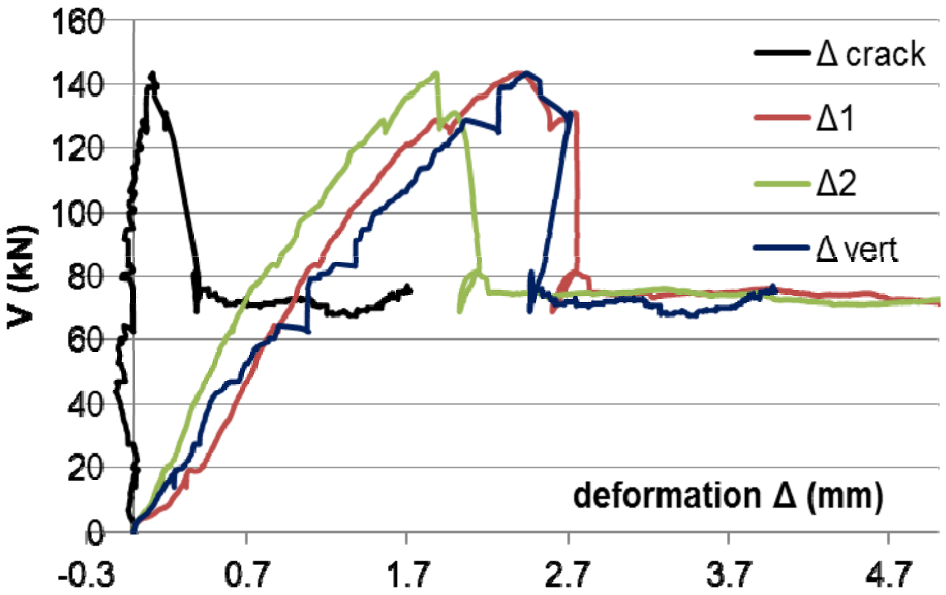
d)

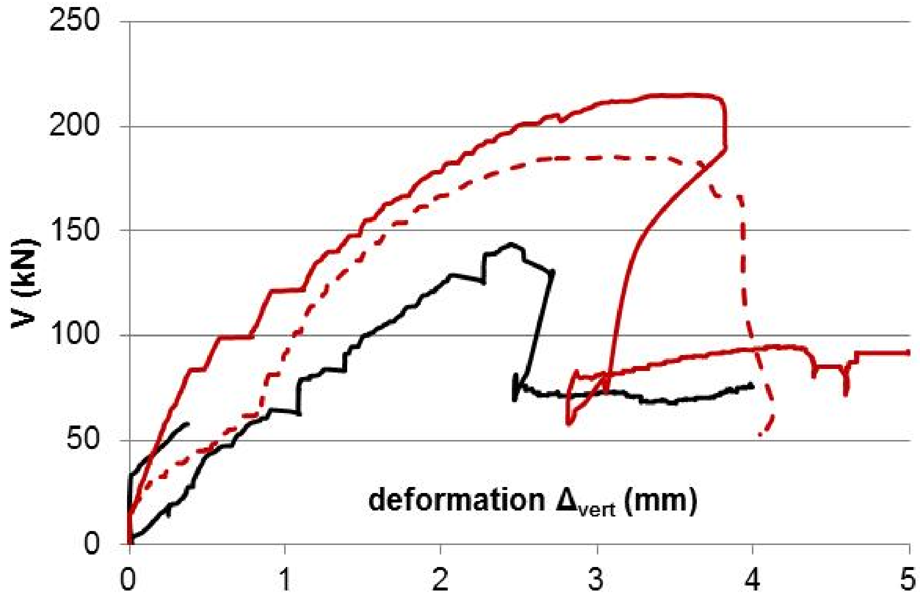


e)

NO fibers/NO stirrups P=60kN, τ=2.5MPa, γ=0.5/200=0.25%
NO fibers/Stirrups P=140kN, τ=5,8MPa

Fibers/NO stirrups P=180kN, τ=7,5MPa, γ=3.5/200=1.75%
Fibers/Stirrups P=200kN, τ=8,3MPa



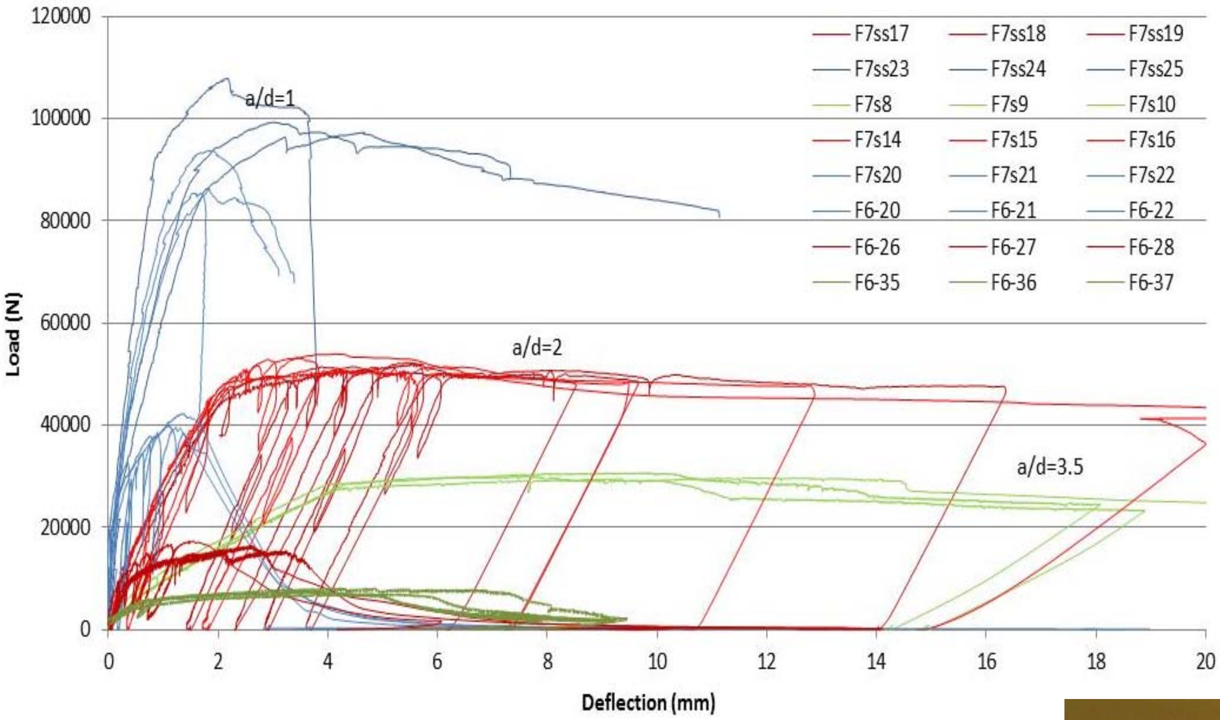


Conclusions

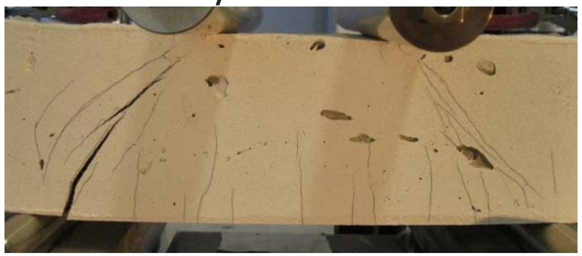
- **Sustainability** is a combination of the **structural design** by increasing the life time of structures and the **material design** in order to decrease the exploitation of resources
- Shorter life time of structures is more costly and resource intensive/greater maintenance costs required.
- In this research it was shown that the combined effect of the use of **high volume fly ash** composites and the use of **short discontinuous fibers** results in materials that exhibit **enormous ductility** in tension, compression, shear and flexure if compared to normal concrete.
- Important products for a more ecological design of structures is **fly ash**
- Overall sustainability design **addition of synthetic dispersed fibers:** enhance resilience, deformation capacity, durability and overall resistance of the resulting structure to natural disasters such as earthquakes
- **CO_2 footprint** is substantially reduced while **ductility** and **resilience** are achieved without an inordinate amount of confining steel–reinforcement
- **Compression:** fibers increased by 30% the axial deformation associated with peak load, restrained lateral expansion at peak load and controlled the compression failure giving a stable postpeak descending branch.
- Additionally the improved performance can lead to **more slender member dimensions**, **reduced** amounts of **steel reinforcement** particularly for shear and confinement, easing construction effort and energy requirements.

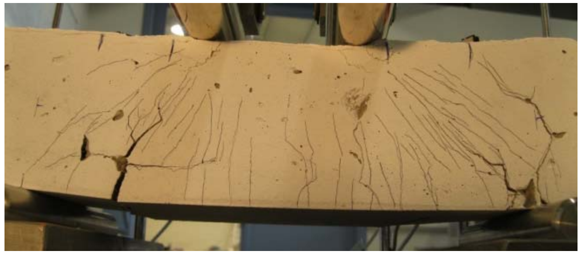
Thank you for your attention

Load-deflection curves



a/d=1





a/d=2

a/d=3.5