Fresh properties of 3D printable Geopolymer Concrete (3DPGPC)

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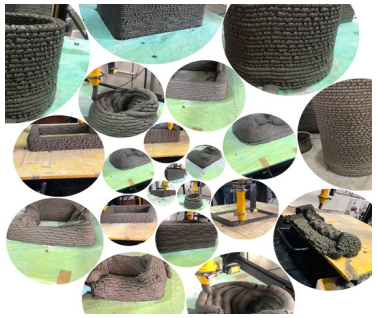

CSIR
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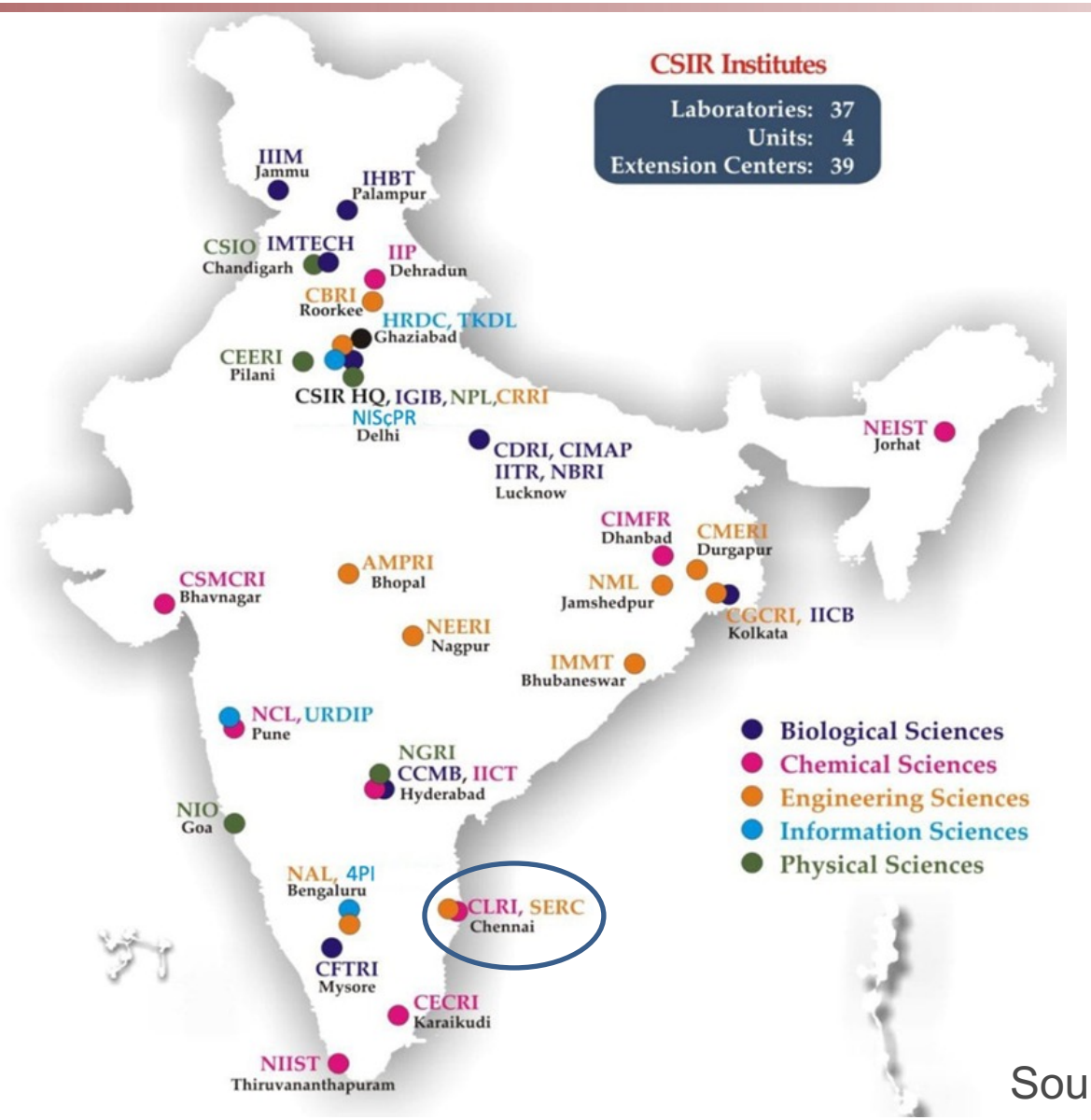


Source: CSIR Website

Project: Advanced Cementitious Composites for 3D Printing

Duration – 5 years (April 2020- March 2025)

Extrusion based 3D concrete printer
1000 mm x 1000 mm x 500 mm

- **3D Concrete Printing (3DCP)** – a type of Additive Manufacturing which uses 3D printing as a core method to fabricate building or construction components.

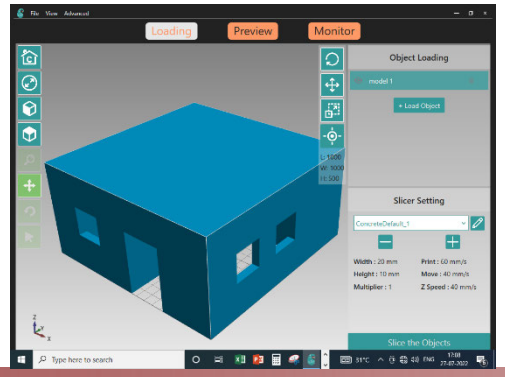
Mixing

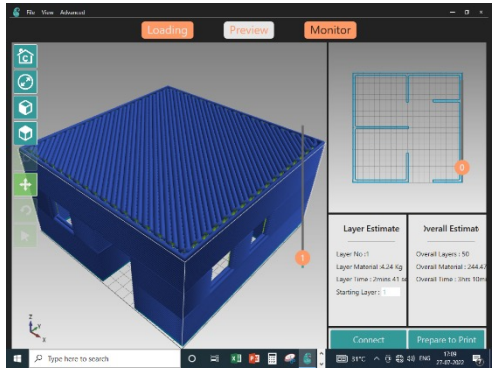
Material Loading/pumping

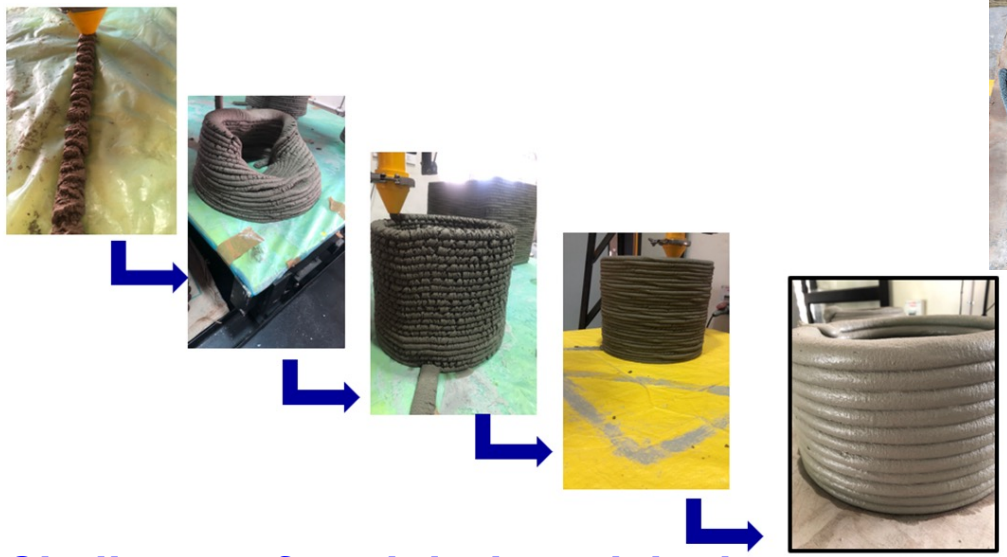
Printing

Printed Object

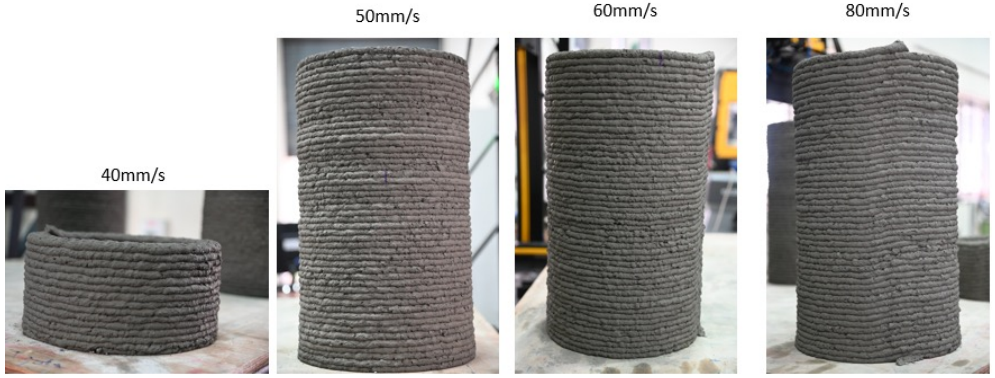
Design and Slicing



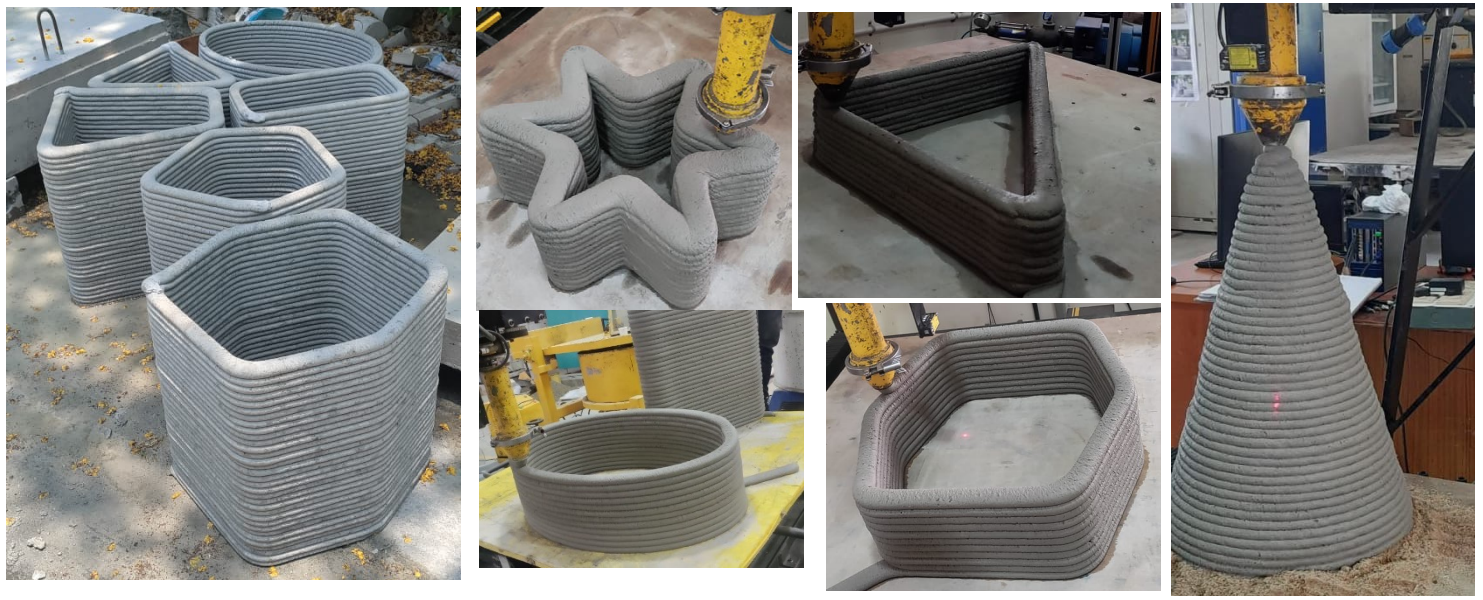




Challenges faced during trial mixes



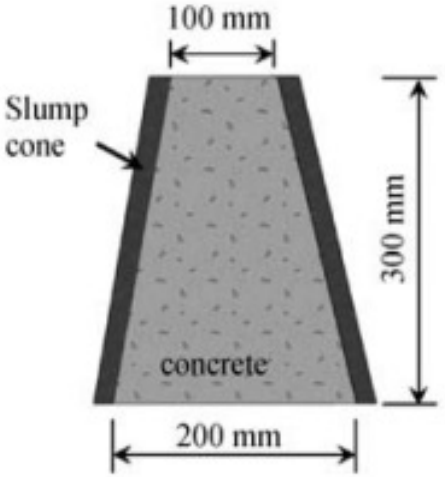
Typical Prints –Mix with coarse aggregate (size 6 mm)



Typical Prints [1 m x 1m] –Mix with fine aggregate

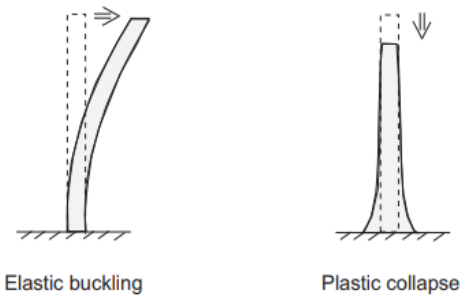
Fresh properties of 3DPC

FLOWABILITY

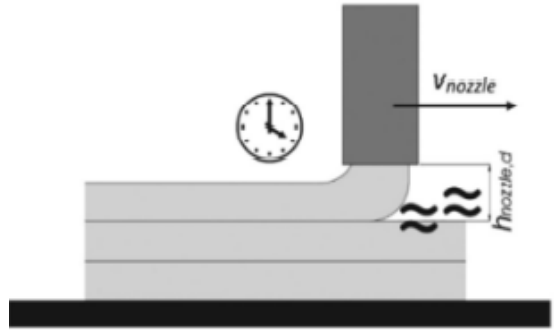


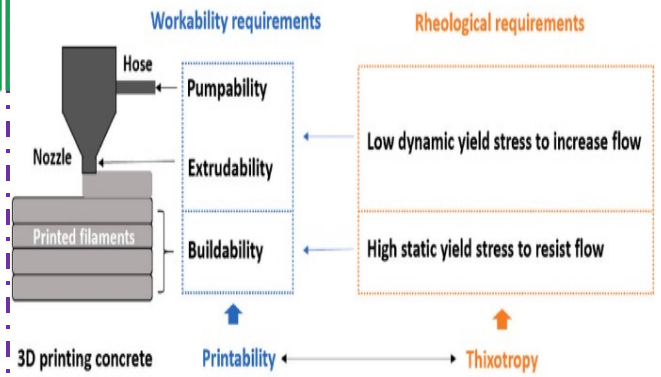
EXTRUDABILITY

BUILDABILITY



OPEN TIME



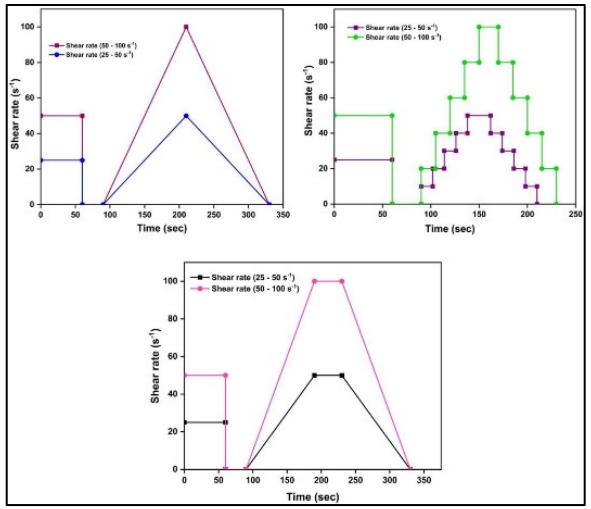


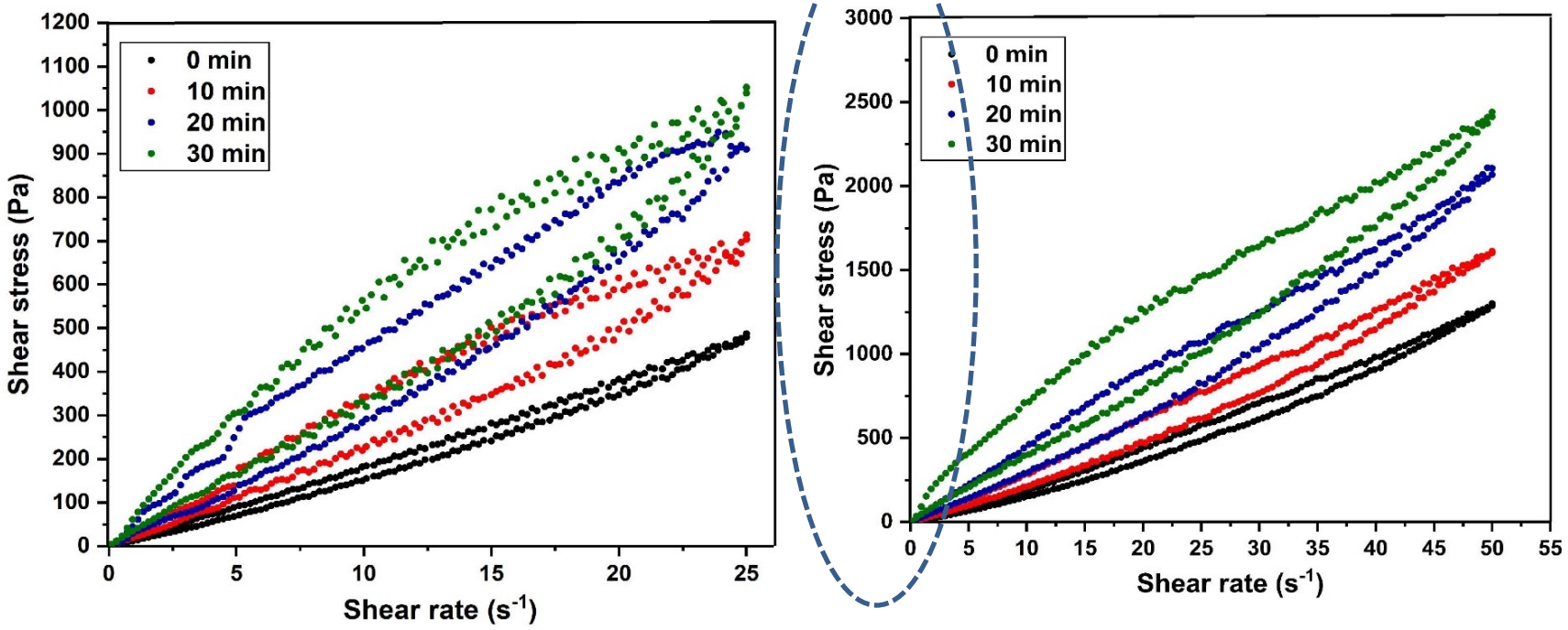
SOURCE: Ma, G., & Wang, L. (2018). A critical review of preparation design and workability measurement of concrete material for largescale 3D printing. *Frontiers of Structural and Civil Engineering*, *12*(3), 382-400.

RHEOLOGY

(a) Rheometer set-up

(b) Two-blade vane spindle





(b) P 1

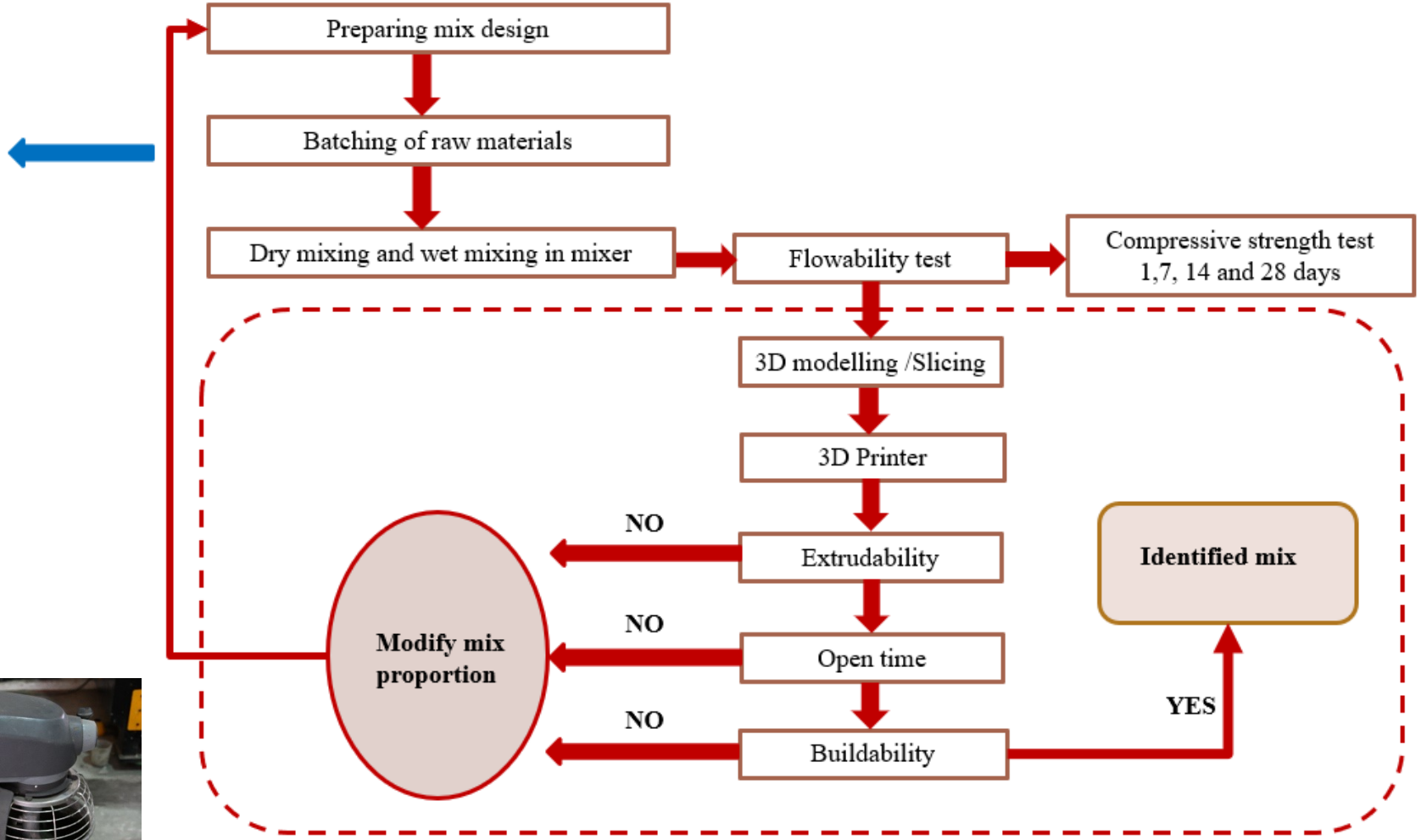
(b) P 2

Fig - Rheological Protocols

Conventional 3DPC

Mixing protocol

- Dry mixing for 3 mins with 36 rpm blade speed
- 85% water added to dry mixture
- After 5 mins, 15% water + SP added
- 10 mins thorough mixing of materials
- Mix fed into hopper of 3D printer



Fresh properties of 3D Printable geopolymer concrete

% Oxide composition of Cement, MBS, SF, FA and GGBS

	Cement	MBS	Silica Fume	Fly Ash	GGBS
Al_2O_3	4.0	0.344	0.159	26.610	16.240
SiO_2	20.49	94.820	94.650	58.440	36.610
CaO	64.7	0.706	0.240	2.896	34.480
CuO	0.013	0.008	0.006	0.015	
Fe_2O_3	4.769	0.199	0.032	6.707	0.584
K_2O	0.673	1.667	2.790	1.281	0.462
MgO	0.732	0.462	0.805	1.100	6.792
MnO	0.071	0.111	0.034	0.089	1.498
Na_2O	0.105	0.081	0.077	0.475	0.235

Physical Properties of Silica Fume, MBS,GGBS and Fly Ash

Property	Silica Fume	MBS	GGBS	Fly Ash
Fineness, m^2/kg	20000	43098	438	500
Loss on Ignition, %	1.5	-	2.1	0.76
Bulk Density, kg/m^3	643	414	1108	700
Specific Gravity, g/cm^3	2.25	2.19	2.9	2.2
Particle size, D50	13	19	25	25

Typical properties of silicates used

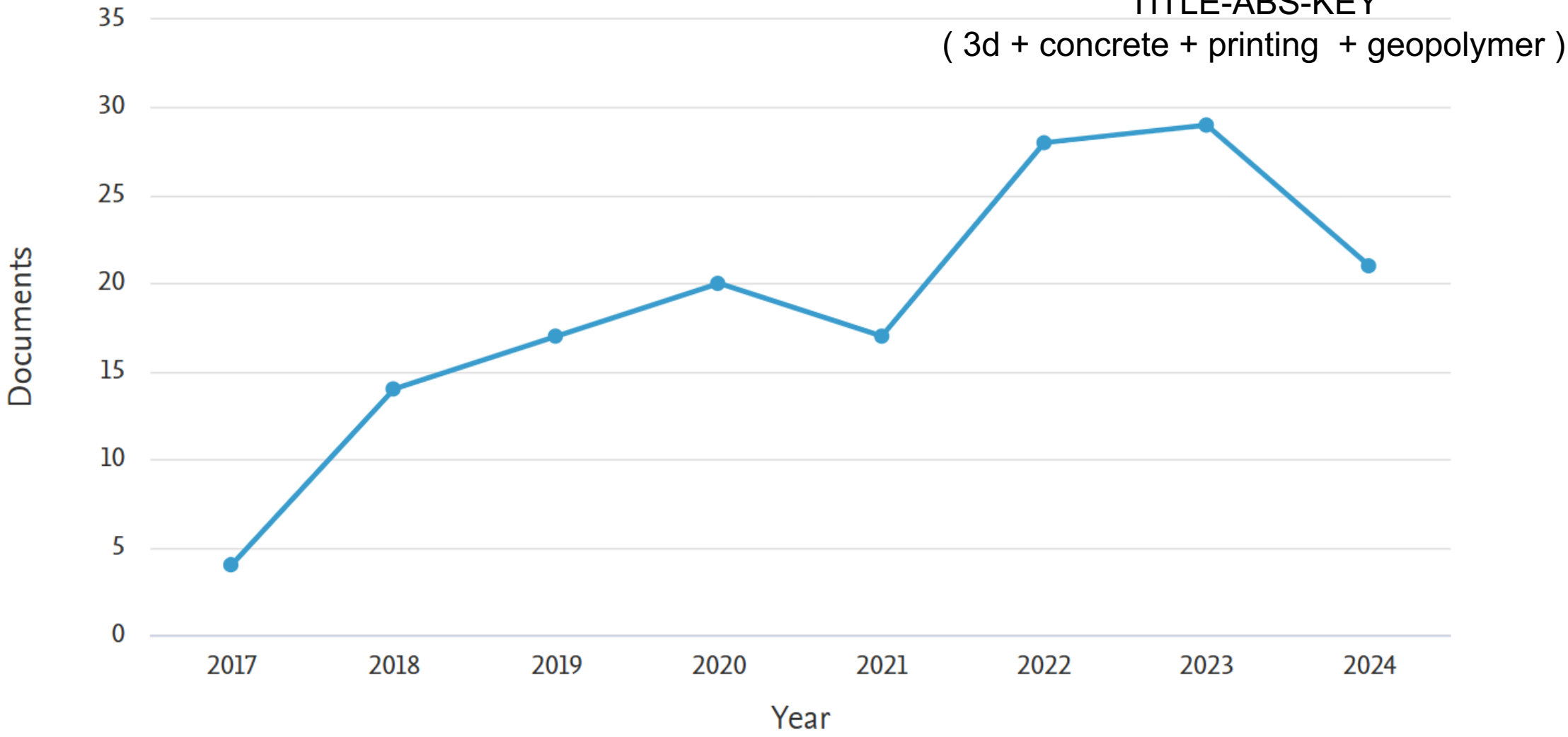
Property	Potassium silicate	Sodium silicate
Specific gravity	1.38	1.50
$\%K_2O$	12.50	-
$\%Na_2O$	-	14.20
$\%SiO_2$	26.30	31.26
%Total solids	38.8	45.46
Baume ^{0}	40	50
Viscosity	440 cp	900 cp

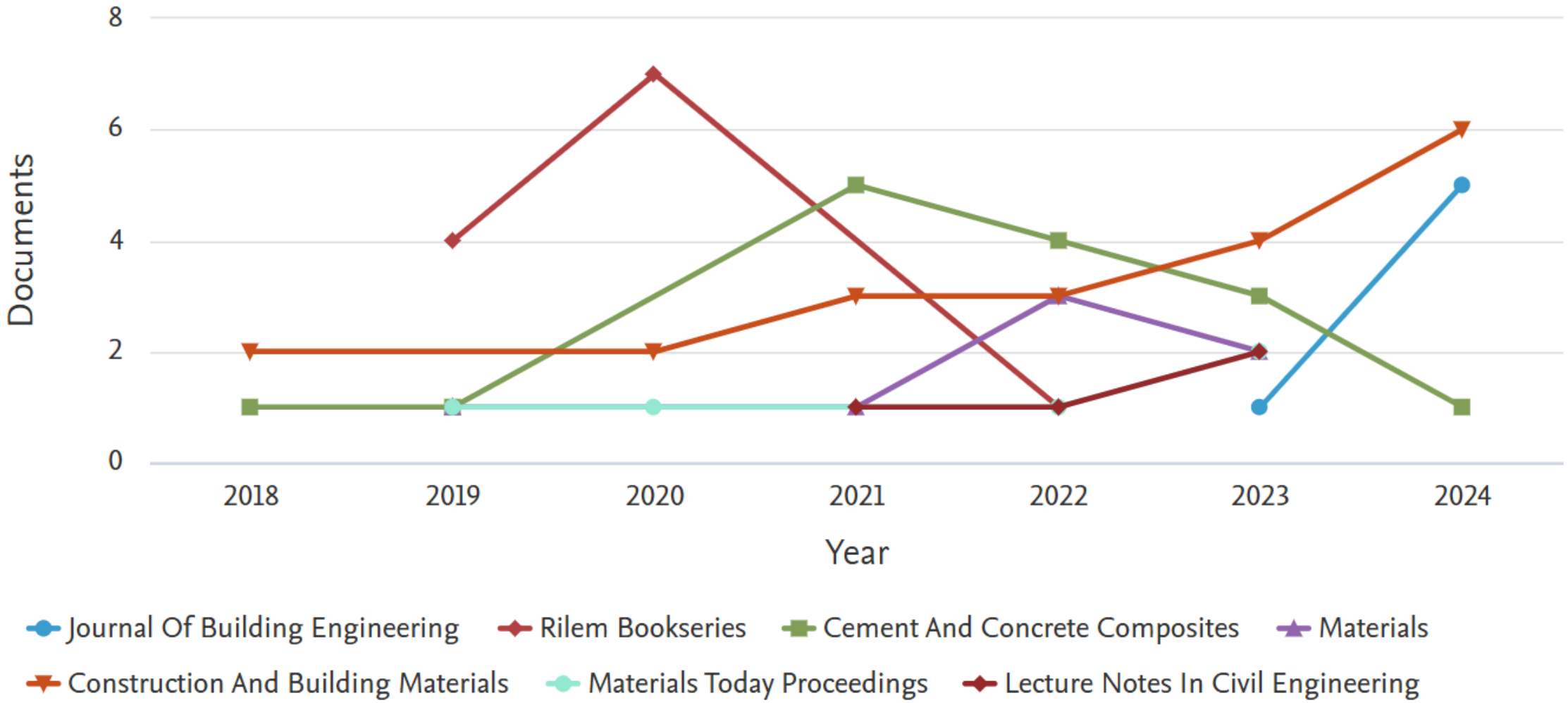
A scientometric analysis

Keywords used for the search

TITLE-ABS-KEY

(3d + concrete + printing + geopolymer)




Documents
8
6
4
2
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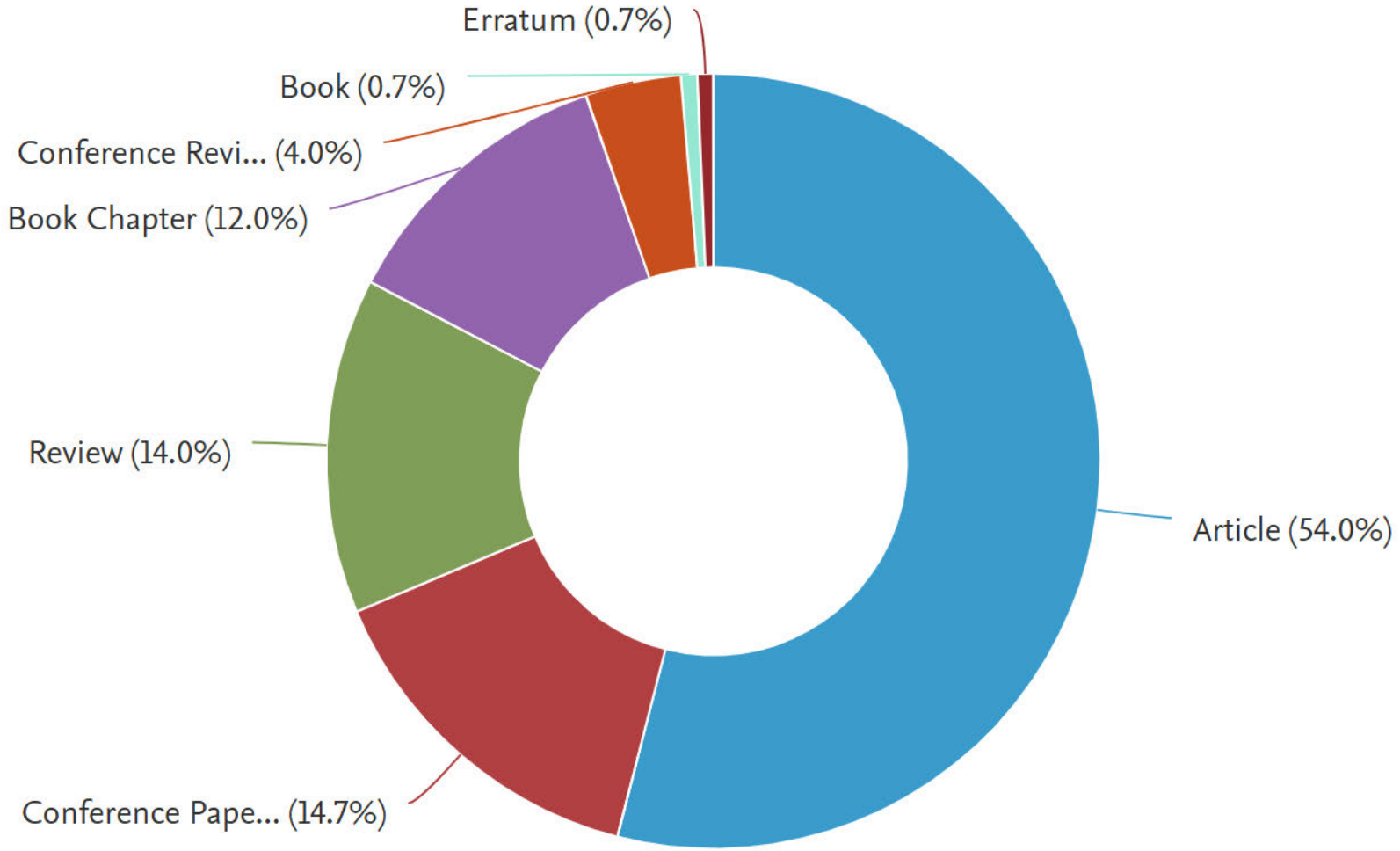
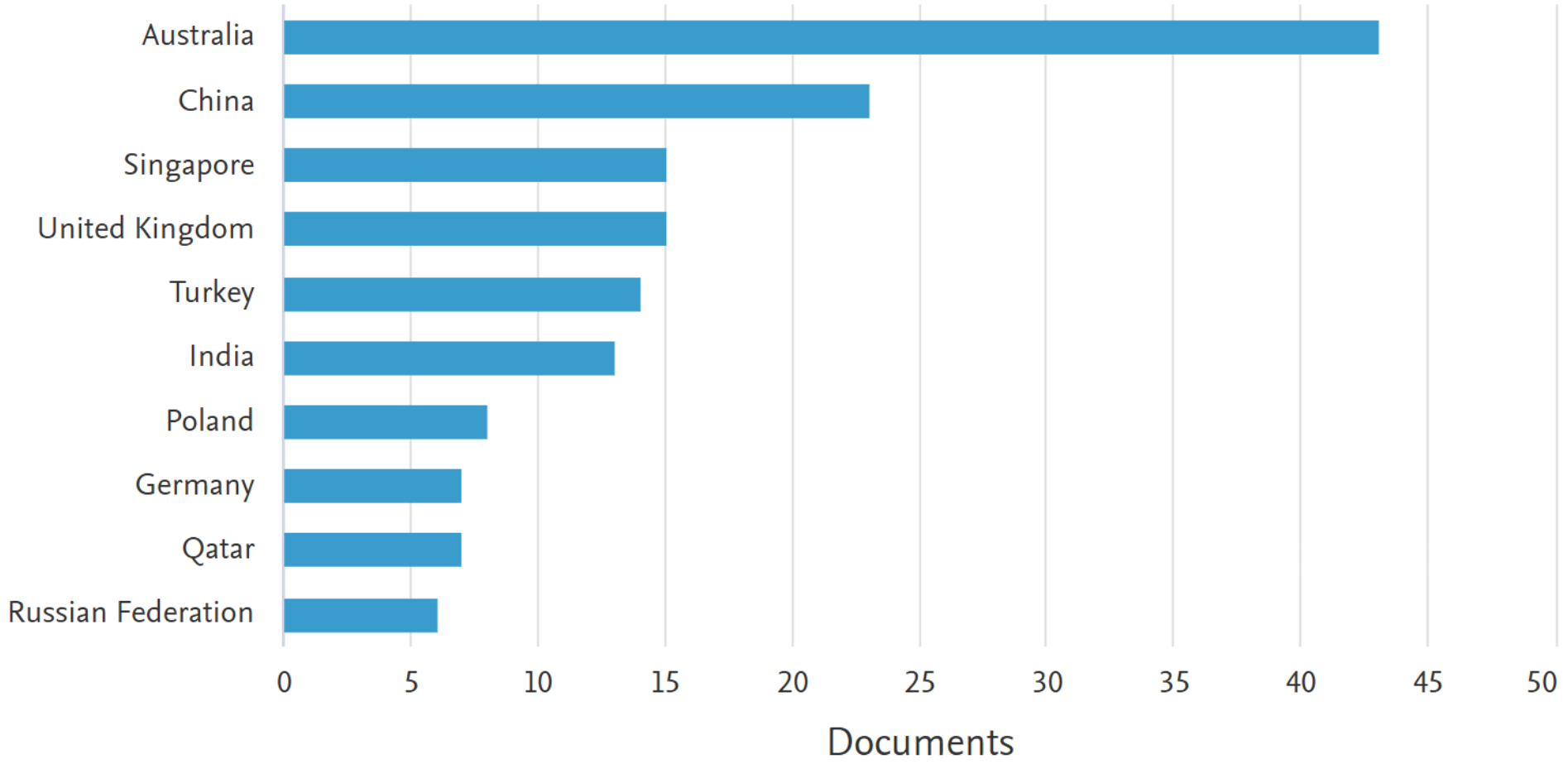
2018
2019
2020
2021
2022
2023
2024
Year
Journal Of Building Engineering
Rilem Bookseries
Cement And Concrete Composites
Materials
Construction And Building Materials
Materials Today Proceedings
Lecture Notes In Civil Engineering

Documents by type

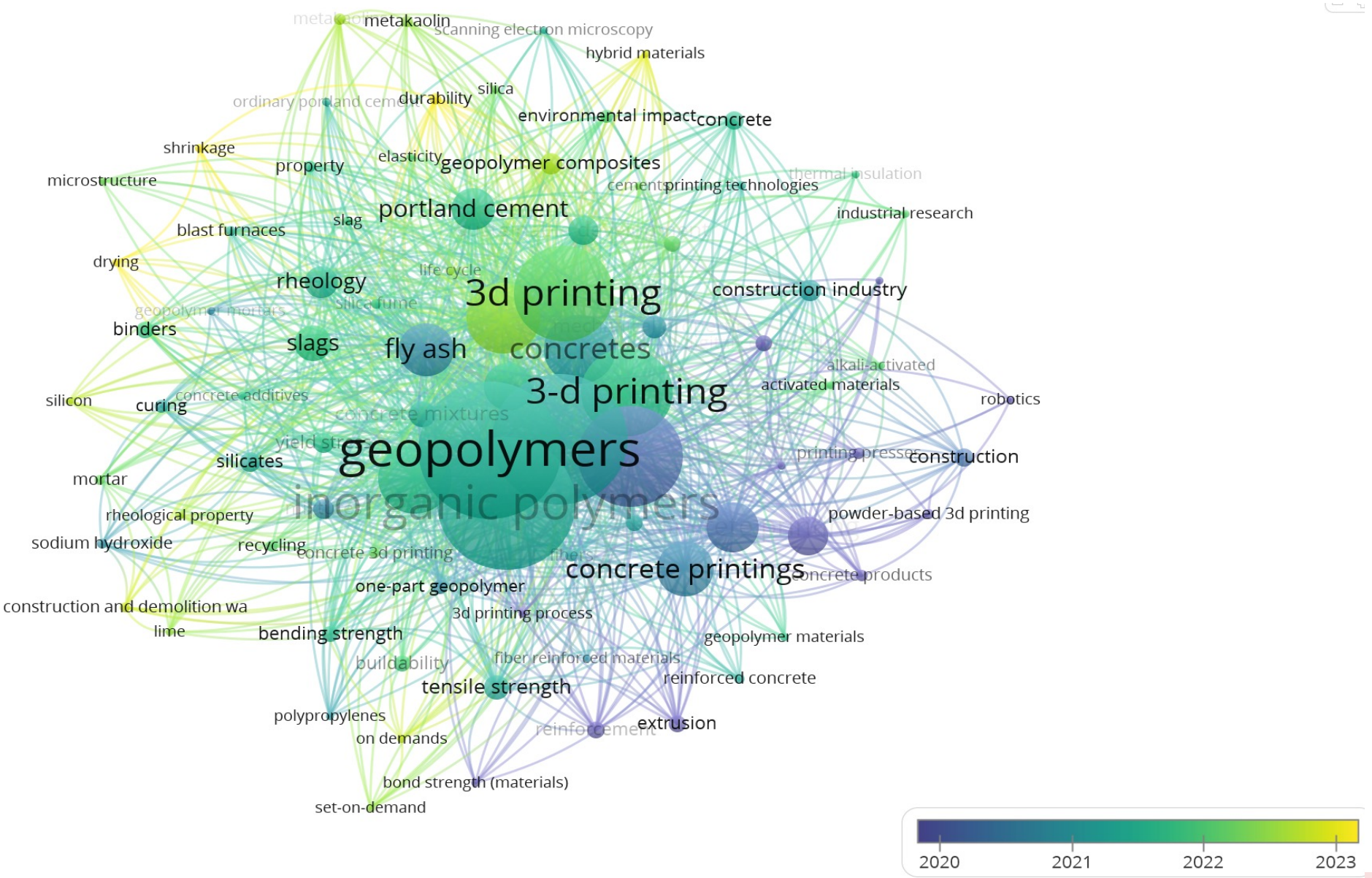


Documents by country or territory

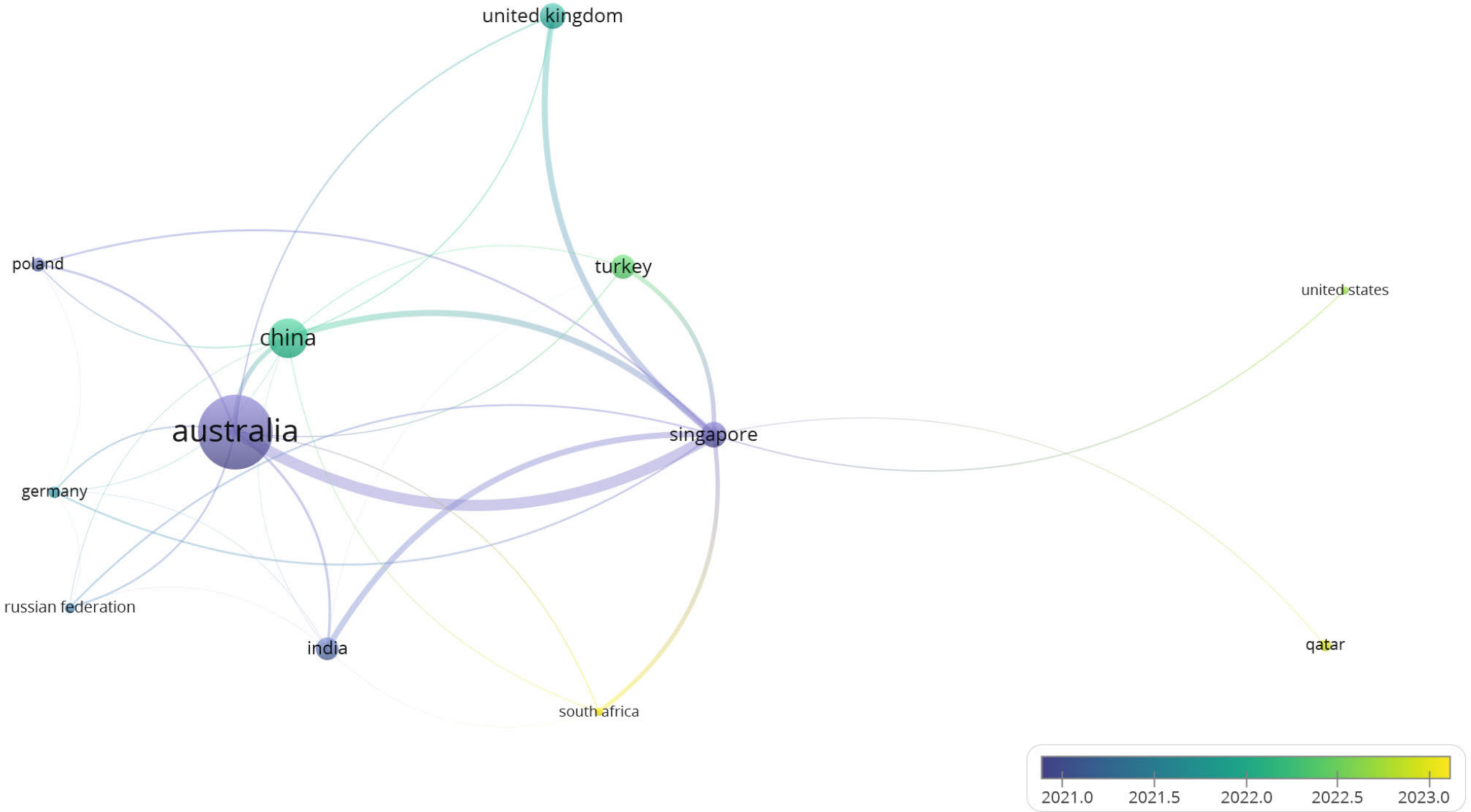
Compare the document counts for up to 15 countries/territories.



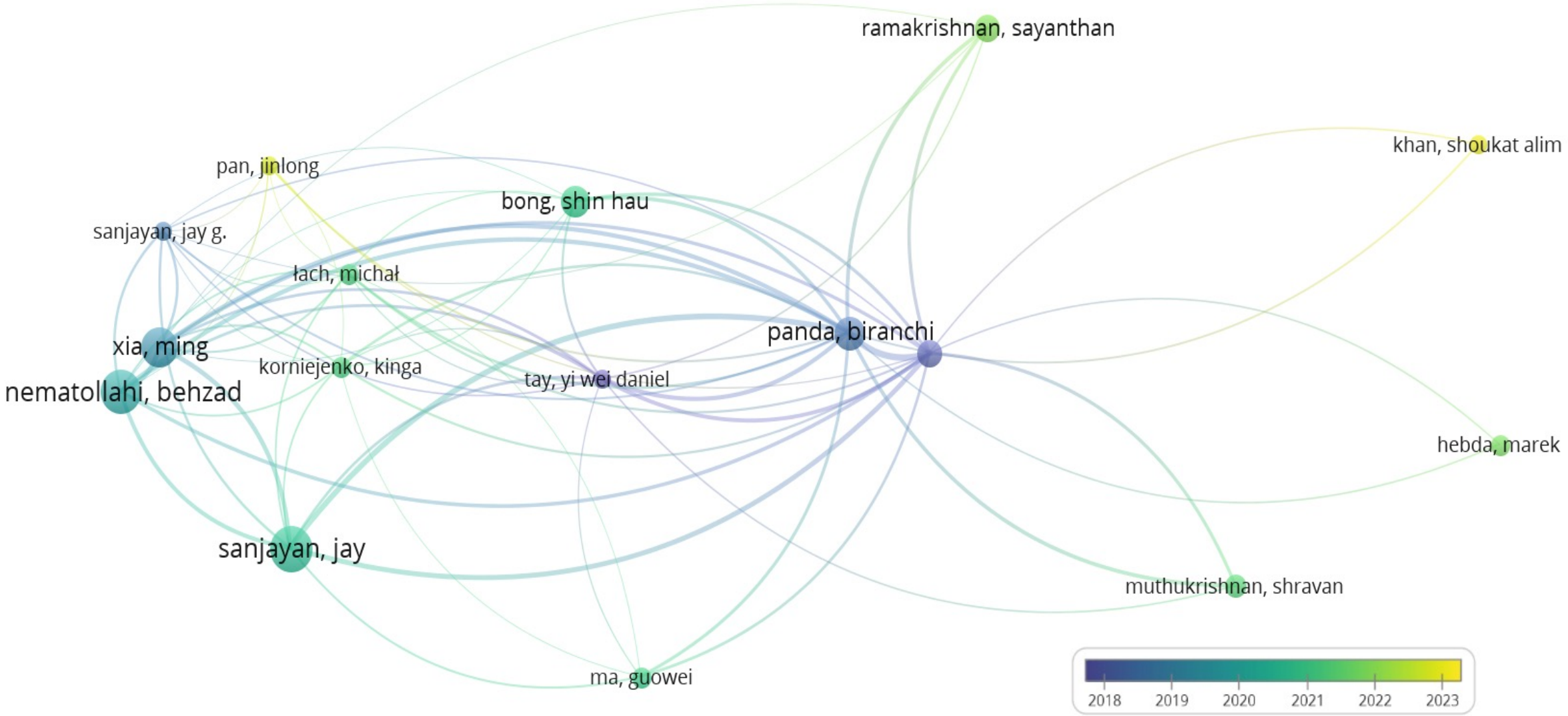
Keyword occurrence in time zone



Country occurrence in time zone



Author occurrence in the time zone



3DGPC- M1 Molarity (M)-0.87 Allkaline Soln/Binder (a/b)-0.38	(High volume fly ash mix) The mix is full flow (More than 1 hour)		3DGPC- M5 M-0.56 a/b-0.35	Reduced molarity to increase the setting time The mix was initially overflowed but stiffened about 23 min		3DGPC- M9 M- 0.56 a/b-0.35	. Lower molarity (0.02b Additional water)	
3DGPC- M2 M-0.87 a/b-0.38	GGBS increased by 10% by reducing fly ash Buildability was not achieving		3DGPC- M6 M-0.87 a/b-0.35	GGBS increased to 10% The mix was stiffed in 15 min. (0.07 addl water)		3DGPC- M10 M-0.56 a/b-0.35	. Lower molarity (0.02b Additional water)	
3DGPC- M3 M-0.87 a/b-0.33	Decreased the Alkaline-binder ratio The mix was stiffed within 8min		3DGPC- M7 M-0.87 a/b-0.35	The mix was stiffed in 15 min		3DGPC- M11 M-0.56 a/b-0.37 (Higher Fly ash)	Maintain the slump (40-45 mm)and flow value (200-220 mm) from 15-105 min	 1d@ 6.5 MPa 3d@ 23.8 MPa
3DGPC- M4 M-0.87 a/b-0.35	Increased the a/b ratio The mix was initially overflowed but stiffed in the range of 20-30 min		3DGPC- M8 M-0.87 a/b-0.37	Increases the Alkaline-binder ratio Buildability was not obtained		3DGPC- M12 M-0.56 a/b-0.37 (10% lesser Fly ash)	Maintain the slump (40-45 mm)and flow value (200-220 mm) from 15-105 min	 1d@ 3.7 MPa 3d@ 10.5 MPa

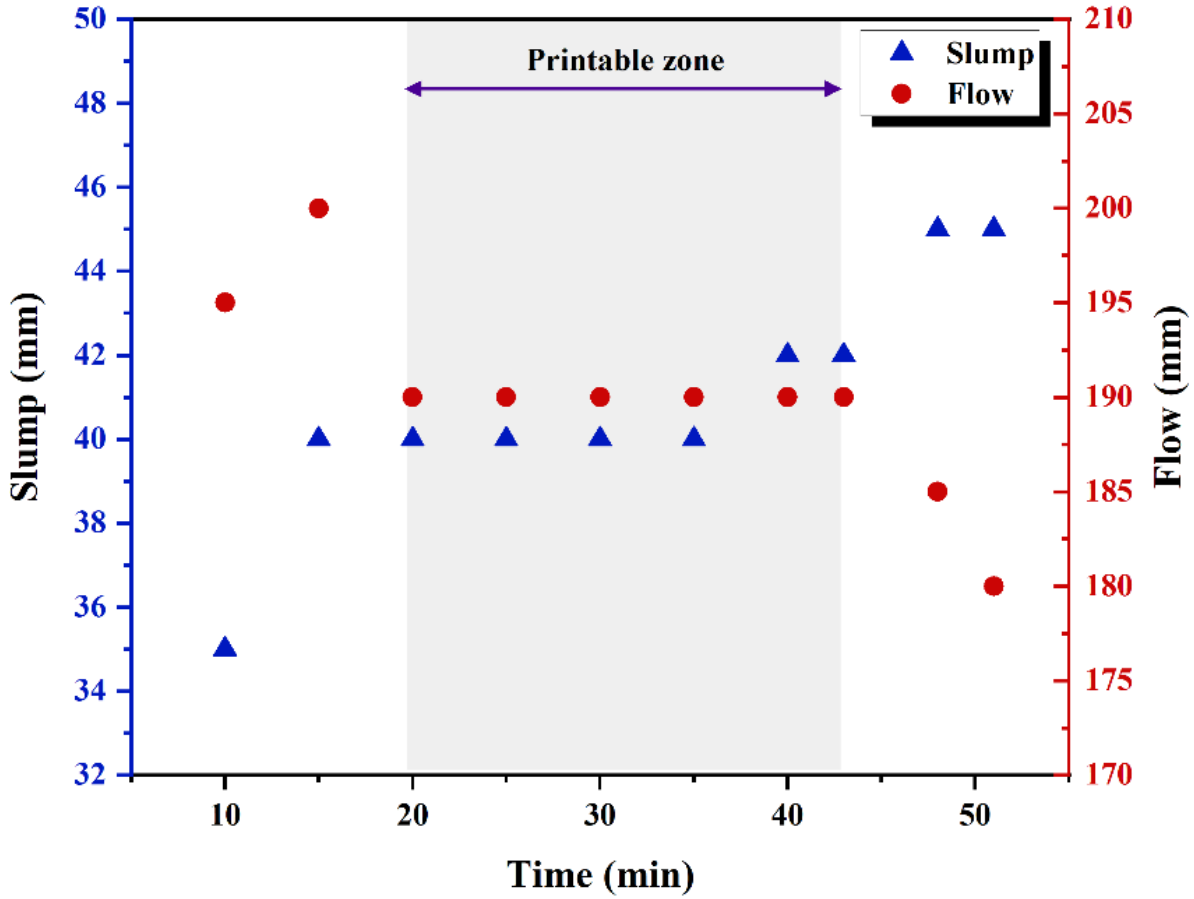
3DGPC- M12 M-0.56 a/b-0.37 (10% lesser Fly ash)	Buildability was not obtained		3DGPC- M16 M-0.87 a/b-0.367	Buildability was not obtained	
3DGPC- M13 (10% lesser Fly ash) M-0.87 a/b-0.36	Maintain the slump (40-45 mm)and flow value (170-185 mm) from 15-60 min		3DGPC- M17 M-0.87 a/b-0.33	Buildability was not obtained	
3DGPC- M14 M-0.87 a/b-0.365	Extrudability was no obtained		3DGPC- M18 M-0.87 a/b-0.36	Initially15-23 min, Buildability was obtained. But after 30 minutes Buildability was not obtained.	
3DGPC- M15 (Higher Fly ash) M-0.87 a/b-0.365	Buildability was not obtained		3DGPC- M19 M-0.87 a/b-0.355	Buildability was obtained. A totally 50 layers were printed	

3DGPC-M19 mixes and Flowability

- However, only the mixture M19 could satisfy the requirements for buildability, extrudability, open time, slump, and flow.
- The slump values are maintained at 40-42 mm between 20 - 45 min
- The flow values are maintained at 190 mm between 20 – 45 min
- So, The Printable zone of the 3DGPC-M19 mix was 20-45 min

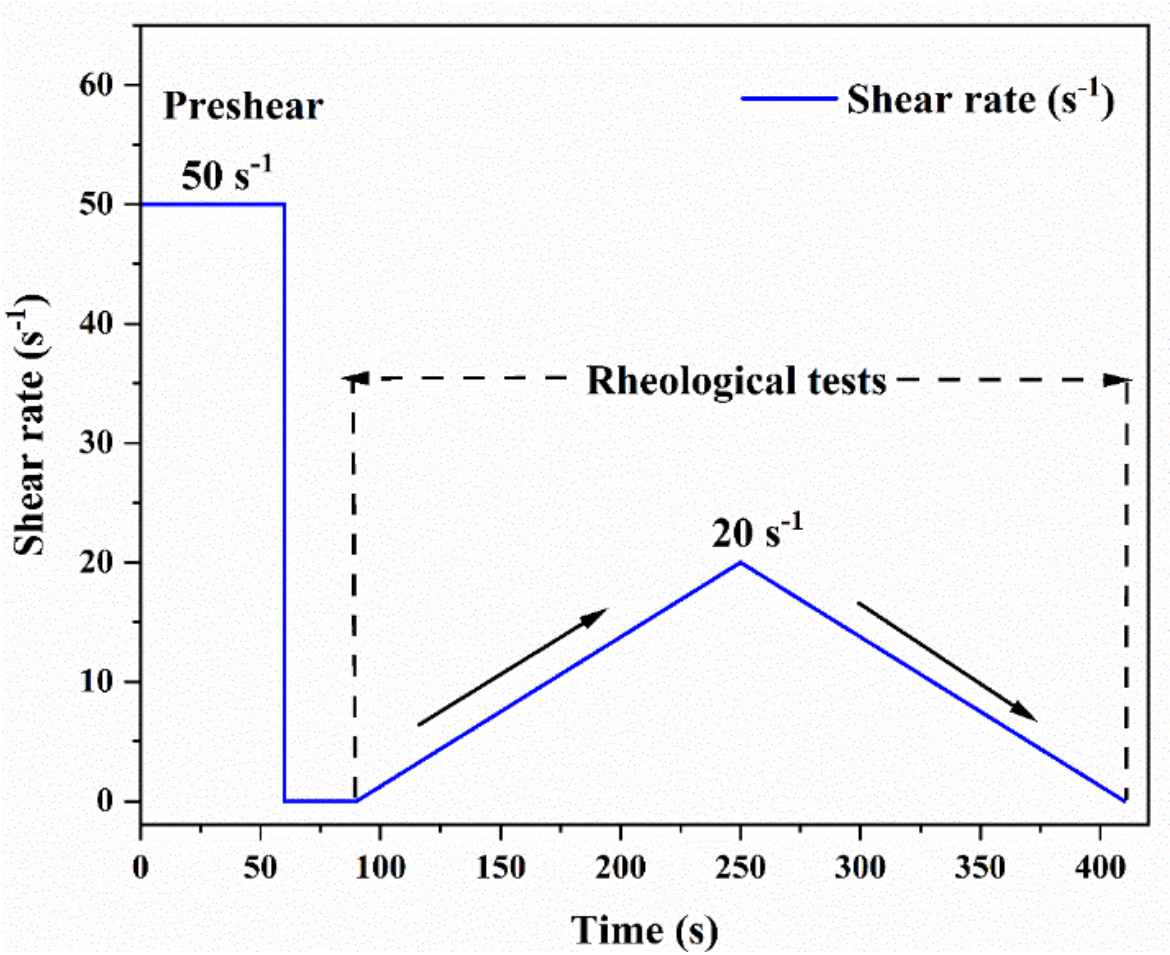
Slump

Flow

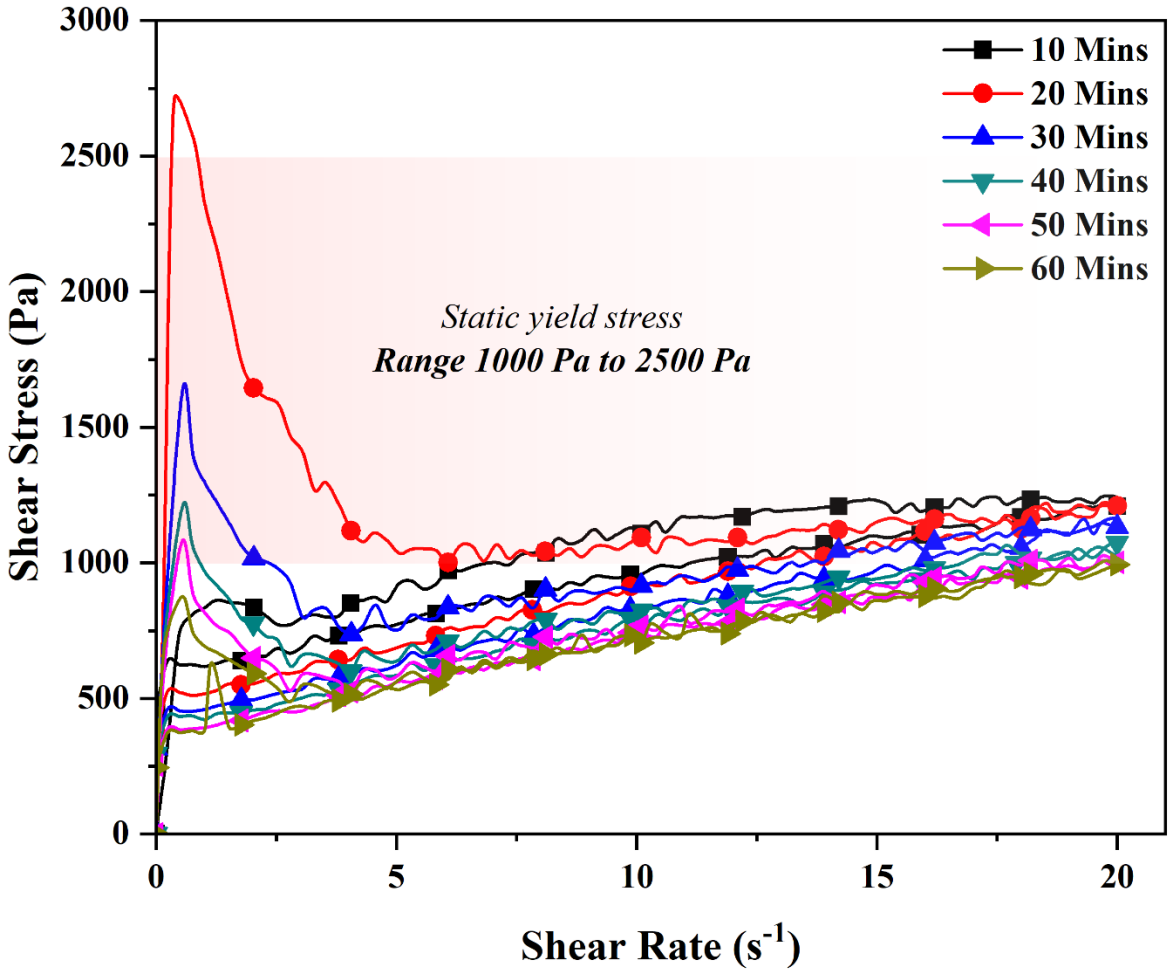


Slump, Flow Vs Time

Rheological Characterization

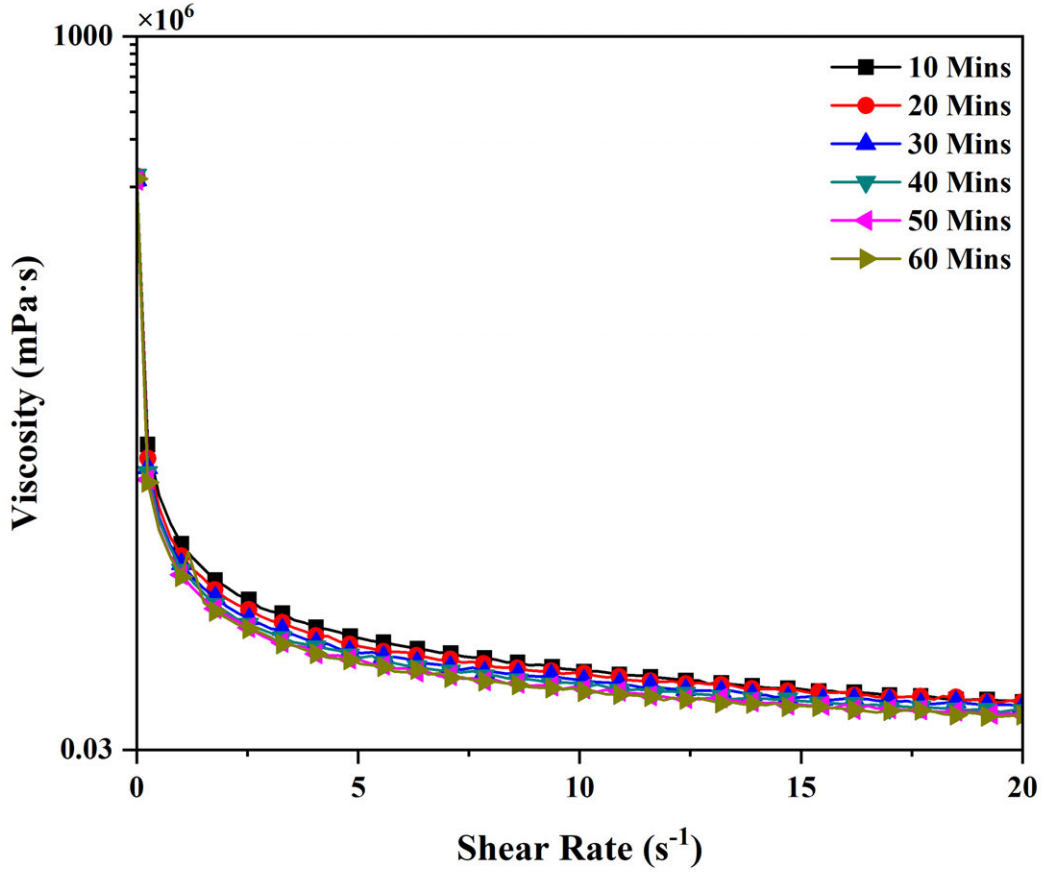


Flow curve protocol

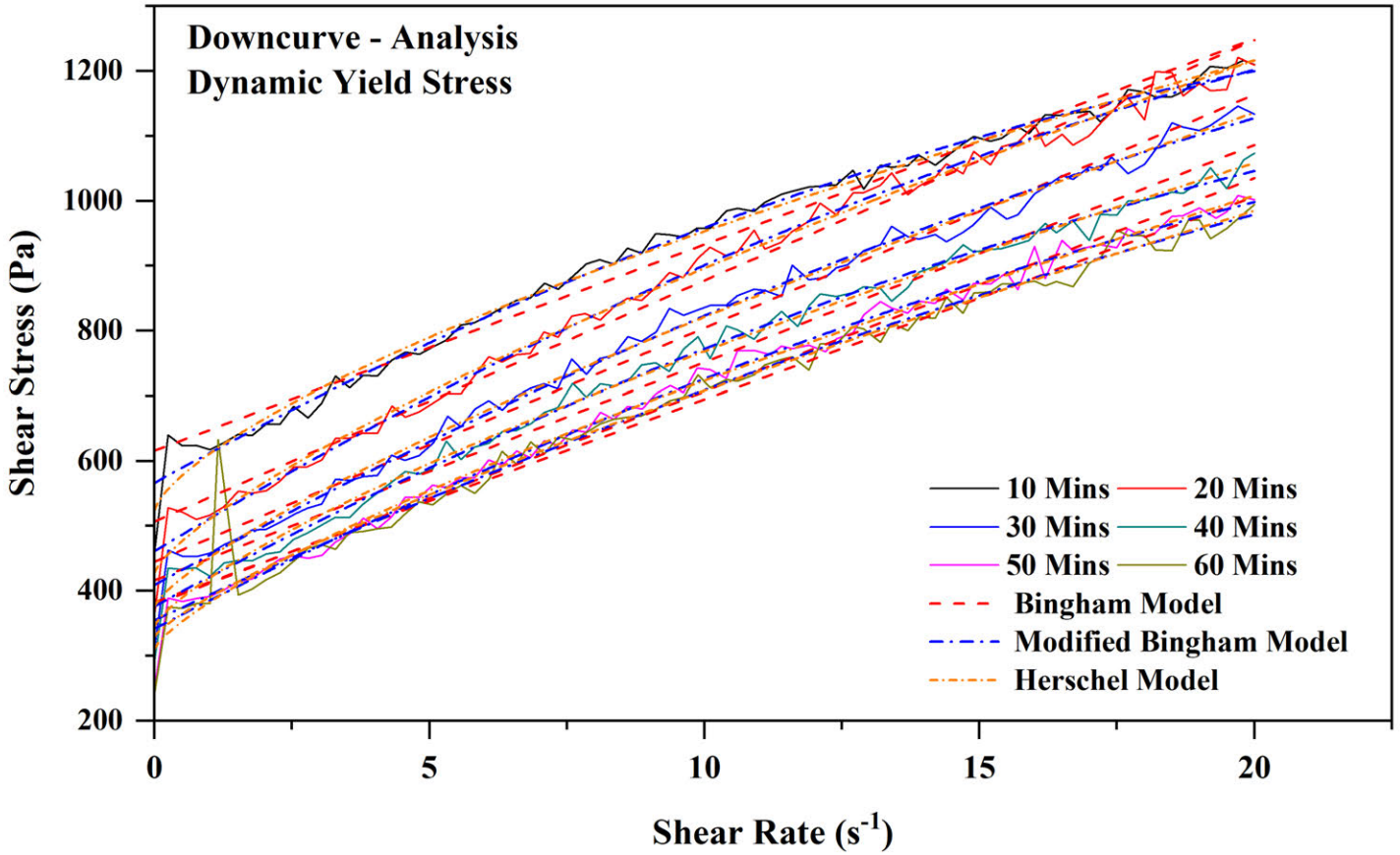


Static yield stress plot

Rheological Characterization



Viscosity vs Shear rate plot

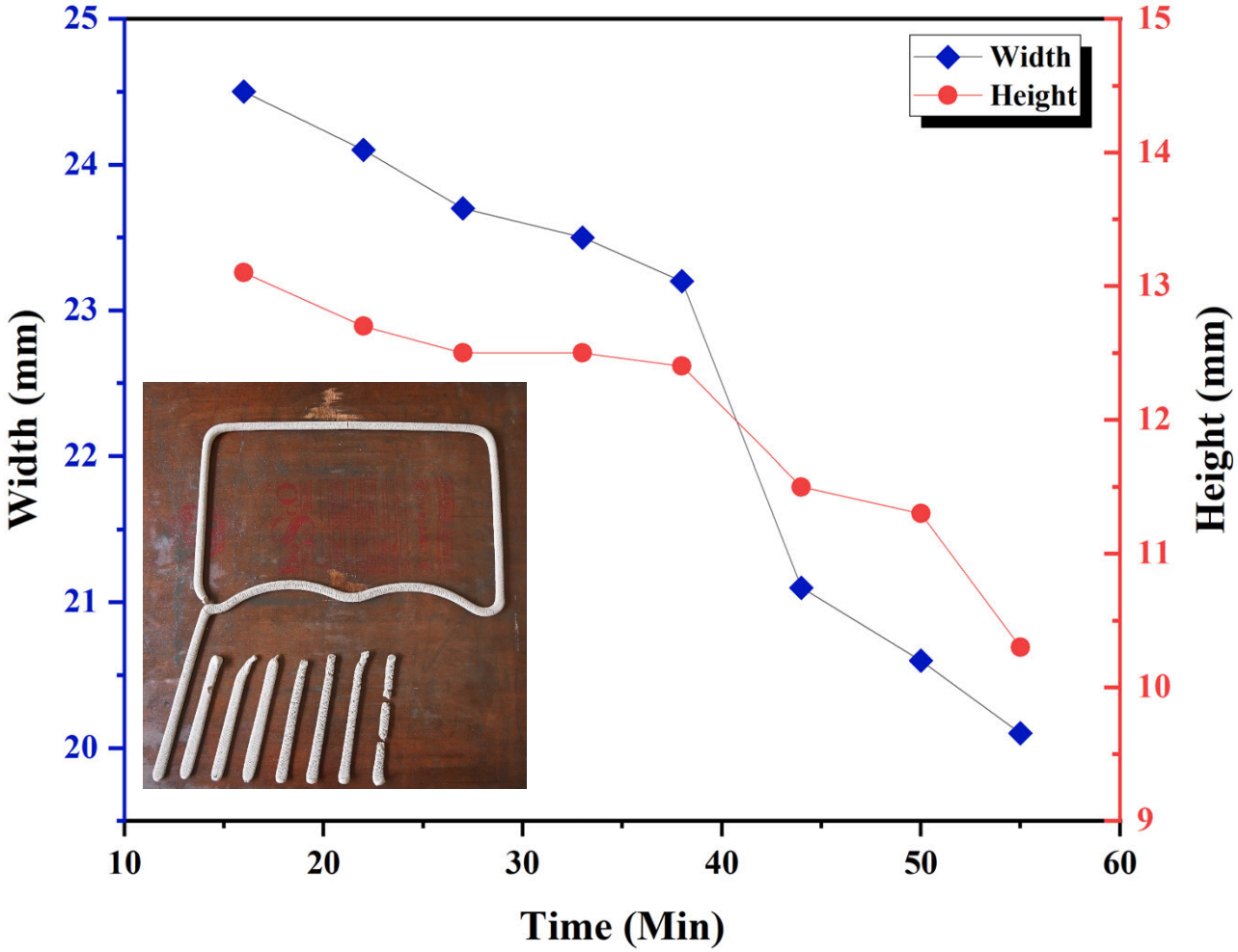


Dynamic Yield Stress - Plot

Model fitting results with R Square values with time dependent

Time (Mins)	Bingham Model			Modified Bingham Model				Herschel – Buckley Model			
	$y = y_o + \mu_p * x$			$y = y_o + \mu_p . x + c.x^2$				$y = y_o + K. x^n;$			
	y_o	μ_p	R^2	y_o	μ_p	c	R^2	y_o	K	n	R^2
10	616.01± 6.51	31.67 ± 0.56	0.9759	**566.24 ± 5.86**	46.79 ± 1.35	-0.75 ± 0.06	0.9911	**522.55 ± 10.92**	88.41 ± 7.24	0.68 ± 0.02	0.9909
20	506.85 ± 6.37	37.03 ± 0.55	0.983	**461.42 ± 6.34**	50.84 ± 1.46	-0.69± 0.07	0.9924	**427.20± 11.00**	83.08 ± 6.70	0.75 ± 0.02	0.992
30	445.097 ± 5.60	35.92 ± 0.48	0.986	**408.97 ± 6.17**	46.89 ± 1.42	-0.54± 0.06	0.9923	**375.72 ± 9.55**	75.45 ± 5.65	0.77 ± 0.02	0.9932
40	416.49 ± 5.67	33.48 ± 0.48	0.9836	**376.34 ± 5.67**	45.69 ± 1.31	-0.61 ± 0.06	0.9925	**345.04± 9.64**	74.77 ± 5.86	0.75 ± 0.02	0.9924
50	378.69 ± 5.26	32.81 ± 0.45	0.9852	**341.79 ± 5.35**	44.02 ± 1.23	-0.56 ± 0.06	0.9931	**309.94 ± 8.67**	72.44 ± 5.24	0.75 ± 0.02	0.9936
60	382.40 ± 7.66	31.20 ± 0.66	0.9661	**354.75 ± 10.54**	39.61 ± 2.43	-0.42 ± 0.11	0.9709	**328.97 ± 16.75**	61.24 ± 9.64	0.79± 0.04	0.9717

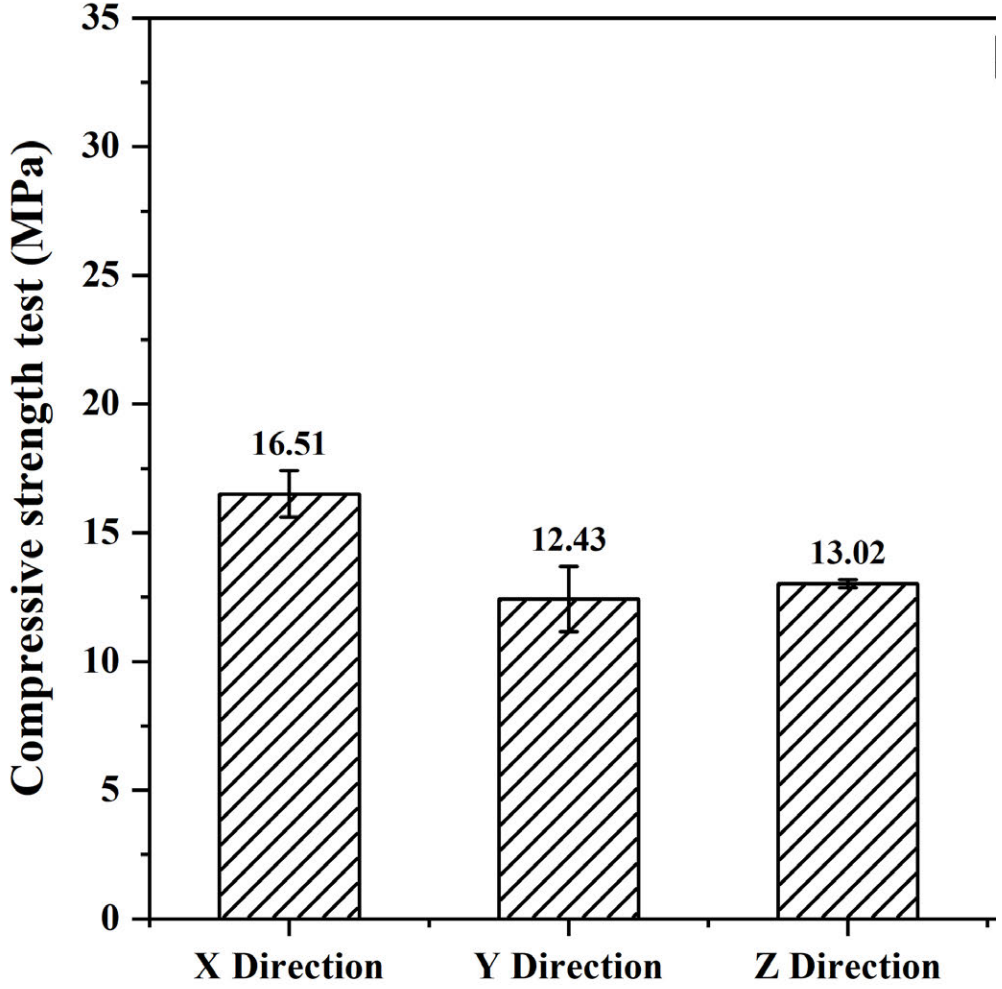
Extrudability, Open Time and Buildability



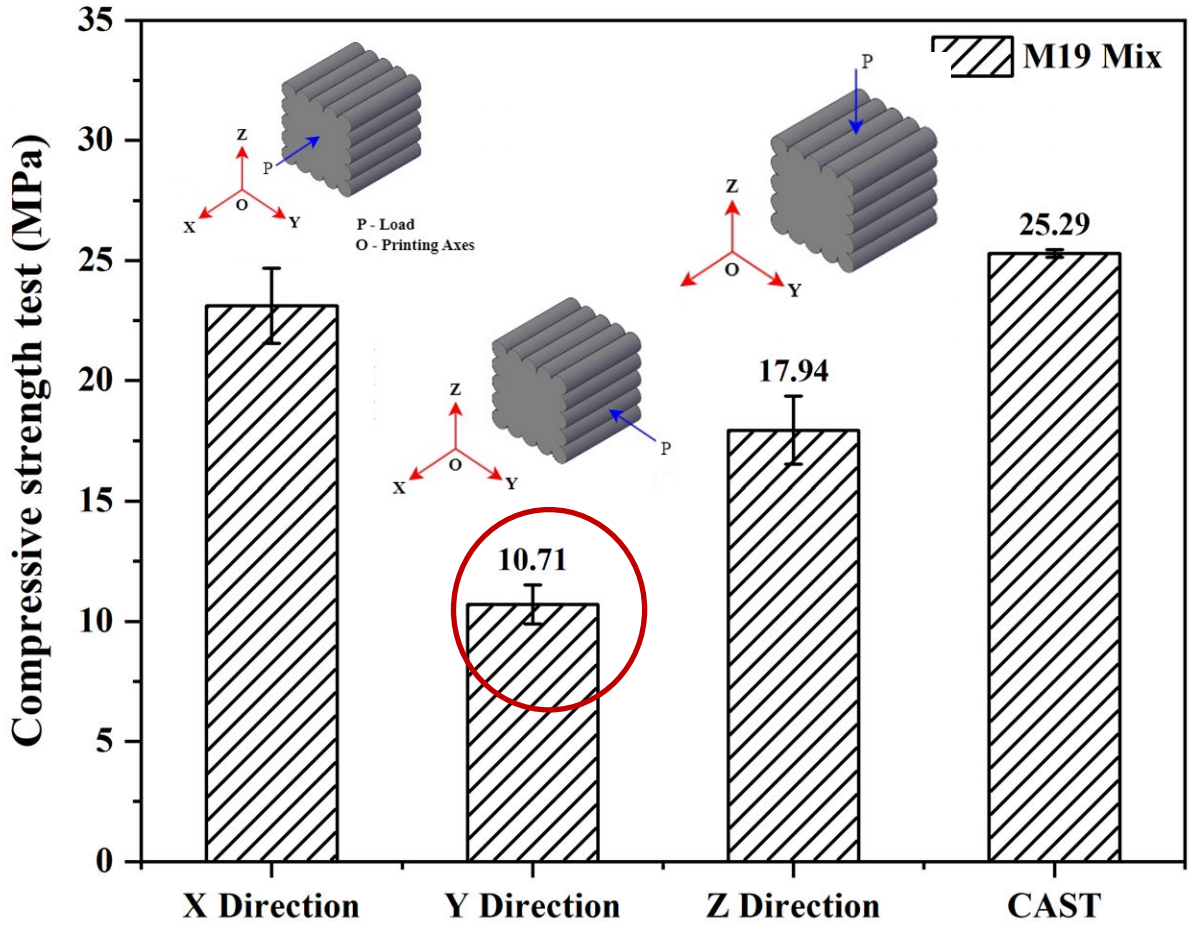
Extrudability

Open Time

Buildability



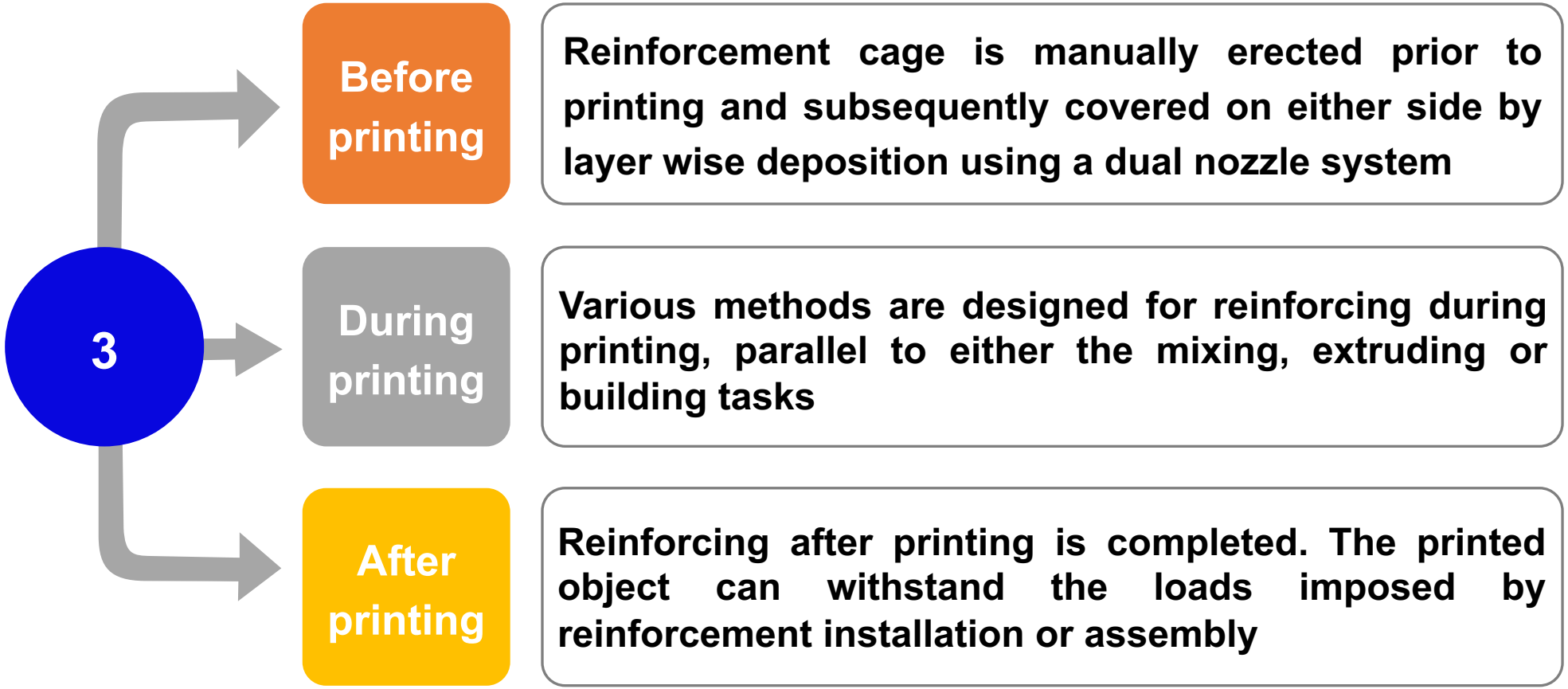
3DGPC samples



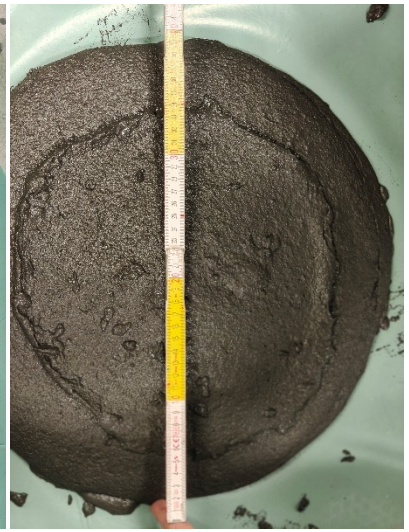
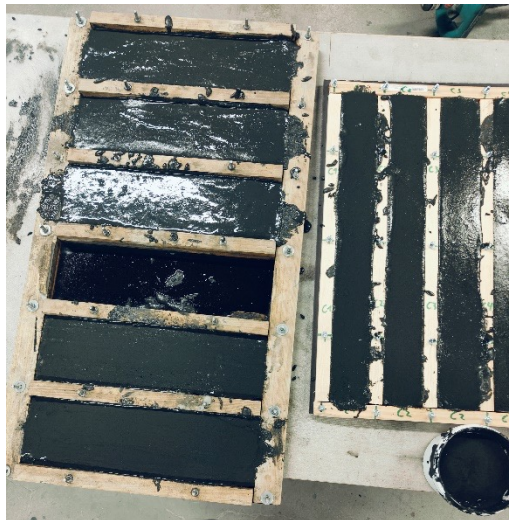
Compressive strength of 3DPGPC (with defects)

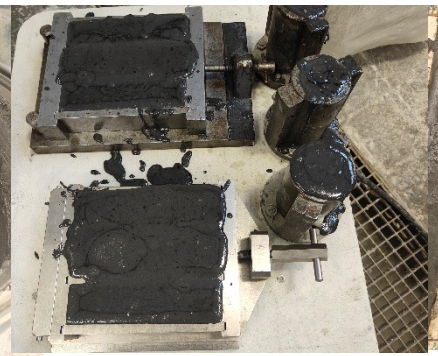
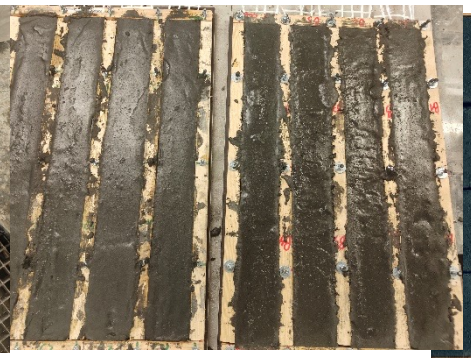
3DGPC-M19 mix used to print map of India

Reinforcement strategies

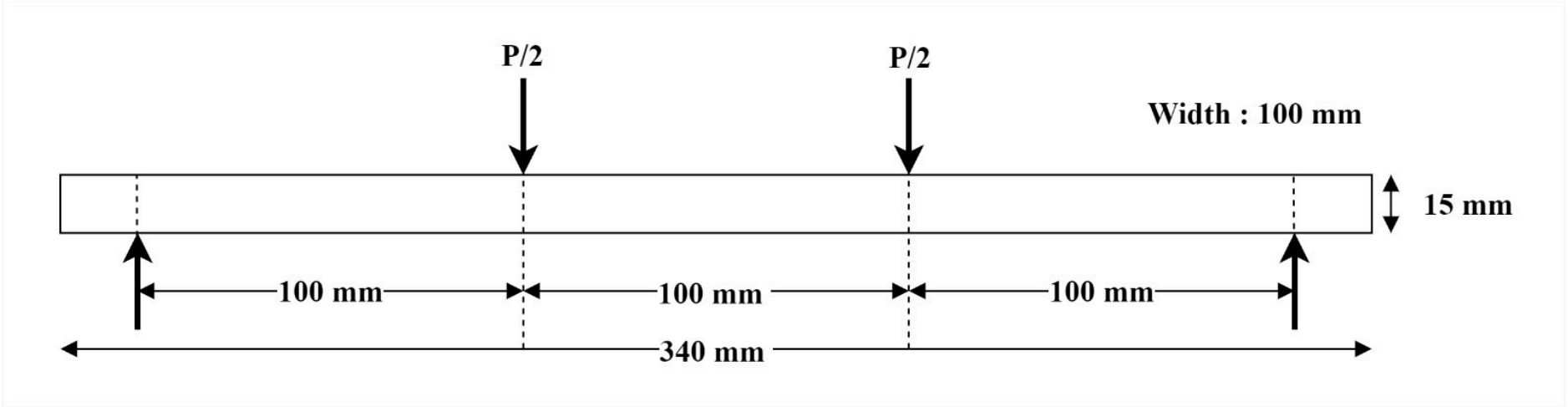


Geopolymer concrete mix casting with (i) without textile (ii) AR Glass coated flexible textile (iii) AR Glass uncoated textile(iv) AR Glass epoxy coated

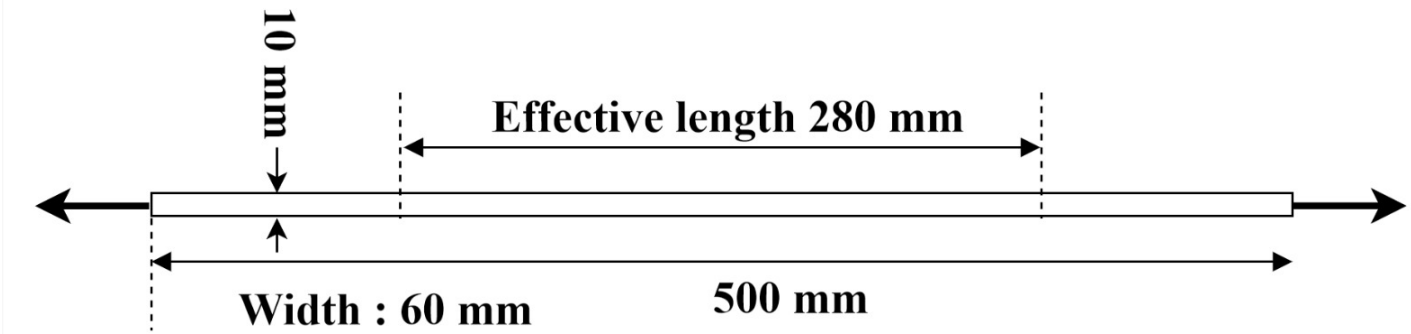




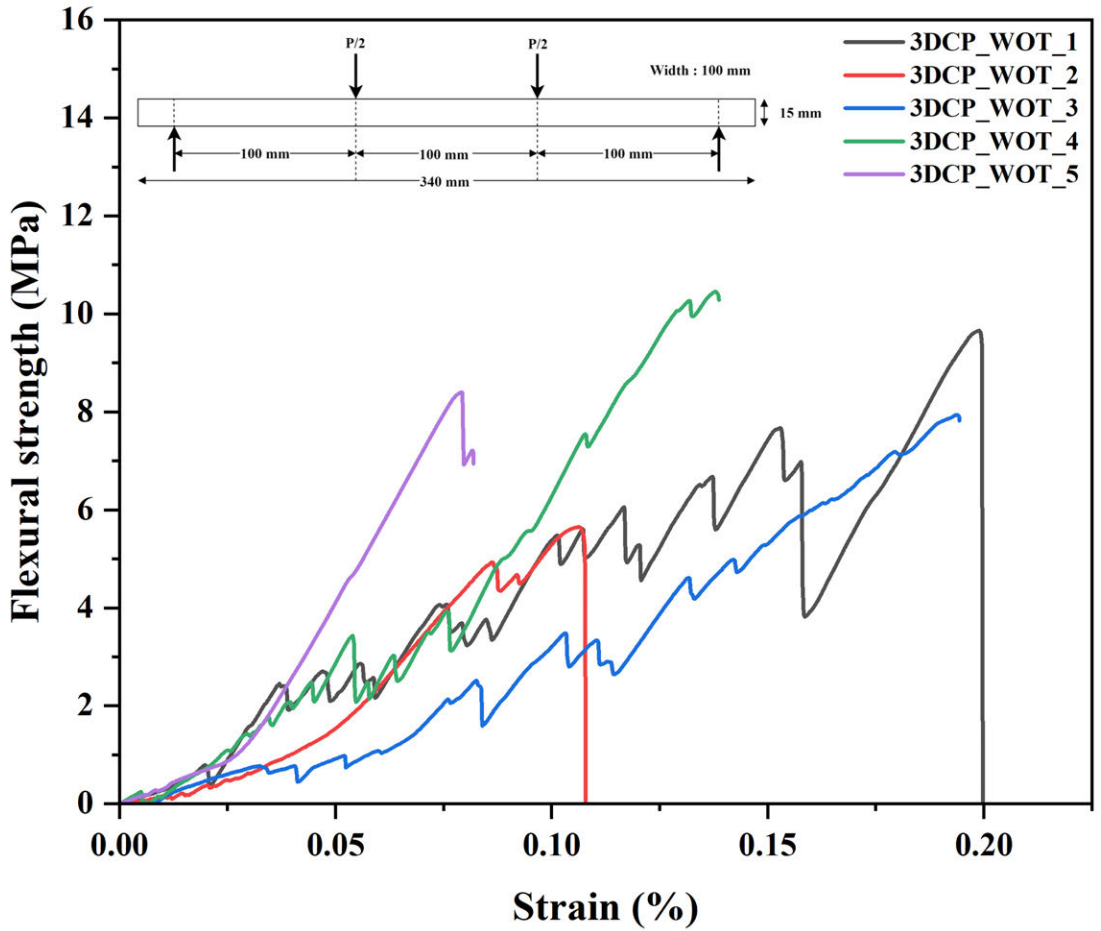
Sl No	Mix ID	Specimen details (mm)	Flow (mm)	Fresh Density (kg/m3)	Property	Remarks
1	3DGP0	i) 340x100x15 -5 no.s ii) 500x60x10 – 4 no.s	400	2296	i) Flexural strength ii) Tensile strength	Geopolymer mortar matrix (Without textile)
2	3DGP1	i) 340x100x15 -5 no.s ii) 500x60x10 – 4 no.s	-	2185	i) Flexural strength ii) Tensile strength	Geopolymer mortar matrix with AR glass coated flexible textile (water 1% of binder increased)
3	3DGP2	i) 340x100x15 -5 no.s ii) 500x60x10 – 4 no.s	380	2275	i) Flexural strength ii) Tensile strength	Geopolymer mortar matrix with AR glass uncoated textile
4	3DGP3	i) 340x100x15 -5 no.s ii) 500x60x10 – 4 no.s	-	2291	i) Flexural strength ii) Tensile strength	Geopolymer mortar matrix with AR glass with coated flexible textile
5	3DGP4	i) 340x100x15 -5 no.s ii) 500x60x10 – 4 no.s	-	2280	i) Flexural strength ii) Tensile strength	Geopolymer mortar matrix with AR glass with epoxy coated textile
6	3DGP5	i) 270x80x20 -5 no.s (1) ii) 270x80x20 -5 no.s (2)	-	2261	i) pull out test	1. Geopolymer mortar matrix with AR glass with coated flexible textile 2.Geopolymer mortar matrix with AR glass with epoxy coated textile



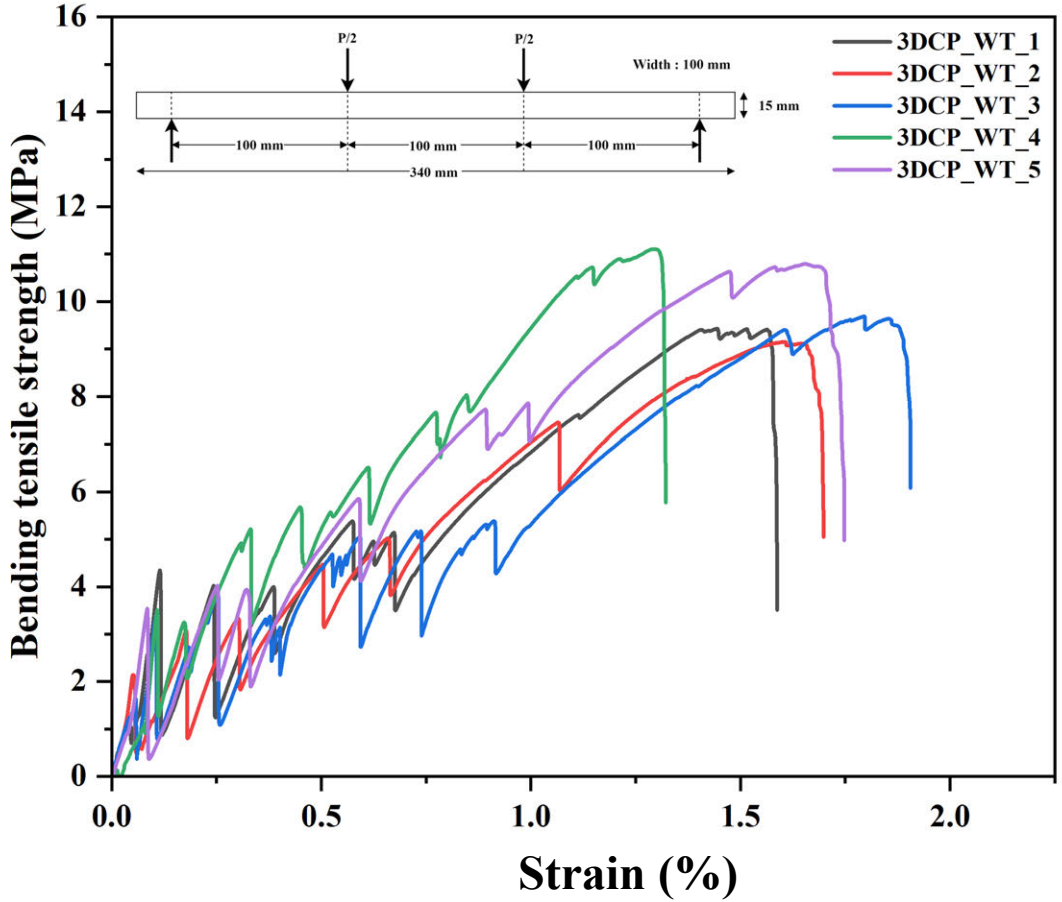
Four point bending test



Direct tension test



Serie n = 5	b mm	h mm	F_{MOR} N	σ_{MOR} MPa	Δ_{MOR} mm	ε_{MOR} %
$\bar{x}$	99,96	18,11	1068,02	9,85	1,32	0,14324



Serie n = 5	b mm	h mm	F_{MOR} N	σ_{MOR} MPa	Δ_{MOR} mm	ε_{MOR} %
$\bar{x}$	100,36	18,97	1363,07	11,34	13,73	1,55921

‘Think Global Act Local’

Thank you!