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The impact of admixtures on the rheological properties of self-compacting concrete with and without fly ash: A review

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Abstract. Although admixtures typically represent only 1–3% of the cement content, they play a crucial role in one cubic meter of concrete. Despite its low proportion, it significantly influences the rheological properties of self-compacting concrete (SCC), particularly in terms of placement, pumping, and segregation resistance, thereby affecting flowability, compressive strength, structural compactness, and durability.

The literature serves as a valuable resource for acquiring the necessary knowledge. A comprehensive synthesis of admixtures was carried out, compiling various results from existing research to deepen the understanding of their impact on the rheology of self-compacting concrete. This study highlighted the determination of a new coefficient, K, which is essential for accurately adjusting the required water content and thus optimizing the rheological properties of concrete.

Key words: Self-compacting concrete (SCC), Rheology, Water, Equivalent water, fly ash, Admixture.

1. Introduction

Self-compacting concrete (SCC) has been widely recognized as a major advancement in concrete technology in recent decades (Ahmad Wani & Ganesh, 2022). The benefits of SCC include reduced labor costs and improved quality control (Sari et al., 1999; Takada et al., 1998). In many cases, SCC outperforms conventional concrete in terms of flowability, strength, structural compactness, and durability (ACI 237R, 2007). Self-compacting concrete can flow under its weight without the need for vibration (Da Silva & De Brito, 2015; Shi et al., 2015). It also facilitates overall project constructability while ensuring optimal structural performance (de Larrard, 1999; Saak et al., 2001). These advancements and advantages cannot be achieved without the use of admixtures. These are often compared to the "spices of concrete" (Kunhi Mohamed et al., 2022). When added in small quantities, these compounds can significantly modify the macroscopic properties of cement and concrete (Aïtcin & Flatt, 2015), thereby playing a crucial role in tailoring concrete mixes for specific applications (Flatt, 2016; Plank & Ilg, 2020). Their use is increasingly favored in the formulation of low-carbon-footprint concrete (Flatt et al., 2012). However, the mechanisms by which these admixtures produce the desired effects are still poorly understood (Kunhi Mohamed et al., 2022). Although progress has been made compared to earlier studies on hydration retardation (Young, 1972) and combining quantitative and rheological approaches for molecular design (Marchon et al., 2017, 2019), many aspects remain unclear. The need to understand the underlying mechanisms is further intensified by the growing demand for sustainable concrete, which is characterized by a high replacement of Portland cement with supplementary cementitious materials (R. Li et al., 2021; Lothenbach et al., 2011; Scrivener et al., 2018). These blended cements generally have lower initial reactivity, thus requiring the use of chemical activators in combination with rheology modifiers, such as superplasticizers. This combination raises competitive adsorption challenges that are crucial to ensure the required combined performance in terms of strength gain and rheology (Bessaies-Bey et al., 2016; Boscaro, 2020; Plank & Winter, 2008; Yamada et al., 2001), particularly in the case of self-compacting

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concrete. Water reducers and high-range water reducers (superplasticizers) reduce the interparticle attraction and produce dispersed suspensions (Aïtcin & Flatt, 2015; Gelardi & Flatt, 2016). Although there are many types of water reducers, comb polymers, mainly based on polycarboxylate ether (PCE), are the most widely used and considered the most advanced products in the market (Plank et al., 2015). The working mechanism of water reducers is primarily understood as being due to steric forces causing the repulsion of cement particles, which is made possible by the adsorption of PCEs on the surfaces of dissolving or precipitating phases (Gelardi & Flatt, 2016; Yoshioka et al., 1997). Another undesirable effect of PCEs is the retardation of cement hydration (Jansen et al., 2012; Marchon et al., 2016, 2017). The exact molecular-level retardation mechanism remains an open question (Kunhi Mohamed et al., 2022), although progress has been made in the so-called delayed addition mode, where the superplasticizer is added shortly after mixing with water (Marchon et al., 2017, 2019). The effect of these additives on hydration is believed to occur by inhibiting either the dissolution of the anhydrous phase or the nucleation and/or growth of hydrates (Garci Juenger & Jennings, 2002; Marchon et al., 2017; Nicoleau & Bertolim, 2016; Suraneni & Flatt, 2015; J. J. Thomas et al., 2009; N. L. Thomas & Birchall, 1983). It is important to note that the mechanism by which retardation occurs may differ among admixtures and may depend on the dose used. Retardation-causing admixtures include simple sugars, such as glucose and sucrose (Kunhi Mohamed et al., 2022). Superplasticizers create the necessary fluidity by attaching to cement particles and inducing an electrical charge, thereby preventing the formation of cement flocs (Aïtcin & Flatt, 2015). However, regarding the fresh-state characteristics of self-compacting concrete, different types of admixtures play an indispensable role in their production, whether they are viscosity-modifying agents, plasticizers, or superplasticizers. Superplasticizers are generally underdosed or overdosed (Bonneau, 1997), which influences the rheological behavior of self-compacting concrete (Bouabdallah, 2025; Bouabdallah et al., 2024). However, underdosing can lead to poorly dispersed Reactive Powder Concrete (RPC) (Richard et al., 1995), and overdosing can cause detrimental countereffects, such as air entrainment and setting delays (Bonneau, 1997). However, excess admixtures can lead to excessive segregation (Hattori, 1979; Uysal et al., 2012), which means that the results depend heavily on the nature of the chemical admixture (Hajime & Masahiro, 2003), whether it is a sulfonated polymer, polycarboxylate, or other synthetic polymer. However, several studies have been conducted on the interaction between cement and admixtures from a physicochemical perspective (Jolicoeur & Simard, 1998), rheology (Banfill, 2011), fresh state, mechanical properties, and durability (S. Singh et al., 2017). The EFNARC has provided guidelines for the design of self-compacting concrete (SCC) mixes (EFNARC, 2002, 2005).

In general, the variability of the admixture percentage, whether a water reducer or a high-range water reducer, relative to cement in the self-compacting concrete formulation, can lead to similar results during various fresh-state tests, which generates confusion among the available information and an enigmatic or vague behavior. A thorough analysis of the impact of different admixture percentages on rheological tests is essential to improve our understanding of superplasticizers. A synthesis study on the formulation of self-compacting concrete represents an ideal opportunity to explore and optimize the use of admixtures to improve their performance. This study analyzed the results of various published studies on self-compacting concrete, focusing particularly on the incorporation of fly ash and other formulations without any additives. After conducting a rigorous literature review, our goal was to understand the impact of admixtures on the rheology of self-compacting concrete based on the available results. We focused mainly on rheological tests, such as the slump flow, T500 flow time, L-box, and V-funnel tests. In conclusion, we identified future challenges and proposed a roadmap to address the key aspects of using these results to better understand the interactions between water, cement, and admixtures.

2. Review Study Methodology

The method used in this synthesis study was the open-access PRISMA (https://www.prisma-statement.org/, 2020)(Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which is often favored for its methodological rigor and transparency. Furthermore, this method allows us to visualize the data in various forms using the advanced features of Excel, which facilitates the communication and presentation of the analysis results.

The first criterion for including or excluding studies grouped in this article was the mention of the quantities of materials used in the composition of SCC, with rheological results such as the slump flow test (ASTM, 2005; BS EN British Standard, 2010b), T500 flow time, L-box test (BS EN British Standard, 2010a), and V-funnel test (BS EN 12350-9:2010, 2010). These tests have proven to be highly effective in controlling the flowability and stability of self-compacting concrete (SCC).

The second criterion focused on a single type of additive, namely fly ash, to exclude the influence of other additives on rheological results.

The third criterion was self-compacting concrete compositions without additives. Often, the authors have developed their own SCC formulation without admixtures based on the available materials and specific objectives of their research. This initial formulation represents the baseline for this study. Subsequently, these authors typically performed a partial substitution of cement with one or two additions. For the baseline formulation, different designations such as NC (Chinthakunta et al., 2021), control (Uysal & Tanyildizi, 2012), S0 (Vilas et al., 2022), and SCC0 (Revilla-cuesta et al., 2022) were used.

Figure 1 presents several articles on self-compacting concrete, extracted from publications by the Elsevier Publishing House. These results stem from our research, which was conducted between 2004 and 2023, and published in various scientific journals. The selection criteria were based on researchers mentioning their formulations in their articles, as well as the results related to the rheology of SCC, whether it contained fly ash or did not contain admixtures.

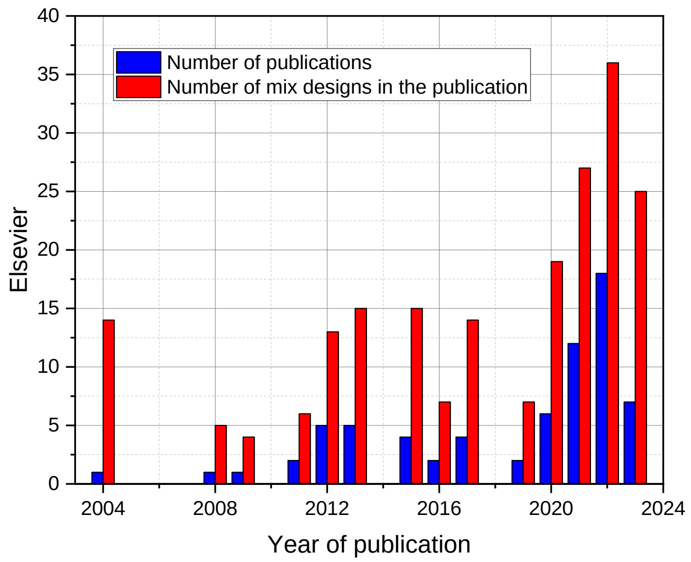

Fig. 1. Publication trend.

Our research strategy aimed to integrate all available articles that met the defined criteria and objectives. The goal was not to analyze all existing articles but to focus on those that shared common points. Among these common points, all authors studied a well-defined SCC mix design, incorporating fly ash with or without admixtures. Another common point is that these studies present their results on rheology, including at least one of the following tests: slump flow tests (ASTM, 2005; BS EN British Standard, 2010b) T500 flow time, L-box test, and V-funnel test (BS EN 12350-9:2010, 2010).

This method of collecting literature data shows that there is no direct link between different researchers, with each study being conducted independently with its own objectives and methods. For example, some studies [53] have investigated(A. Singh et al., 2023) the incorporation of recycled materials into self-compacting concrete, while others (Bani Ardalan et al., 2017) have studied the incorporation of pumice powder into self-compacting concrete. Furthermore, we eliminated repetitions of each mix design used by the authors in multiple articles.

The test results, which are the objectives of this synthesis, represent well-defined tests according to the standards and specifications. The results obtained by researchers on the rheology of SCC are clear. All results were studied and verified in accordance with the international standards and specifications established by the EFNARC (EFNARC, 2002, 2005), which represents the guide for each self-compacting concrete mix design.

Where N_A is the number of articles studied, N is the number of SCC mix designs, N_{FA} is the number of SCC mix designs with fly ash, N_{NA} is the number of mix designs without admixtures, and N_{OA} is the number of SCC mix designs with supplementary cementitious materials (SCMs) other than fly ash.

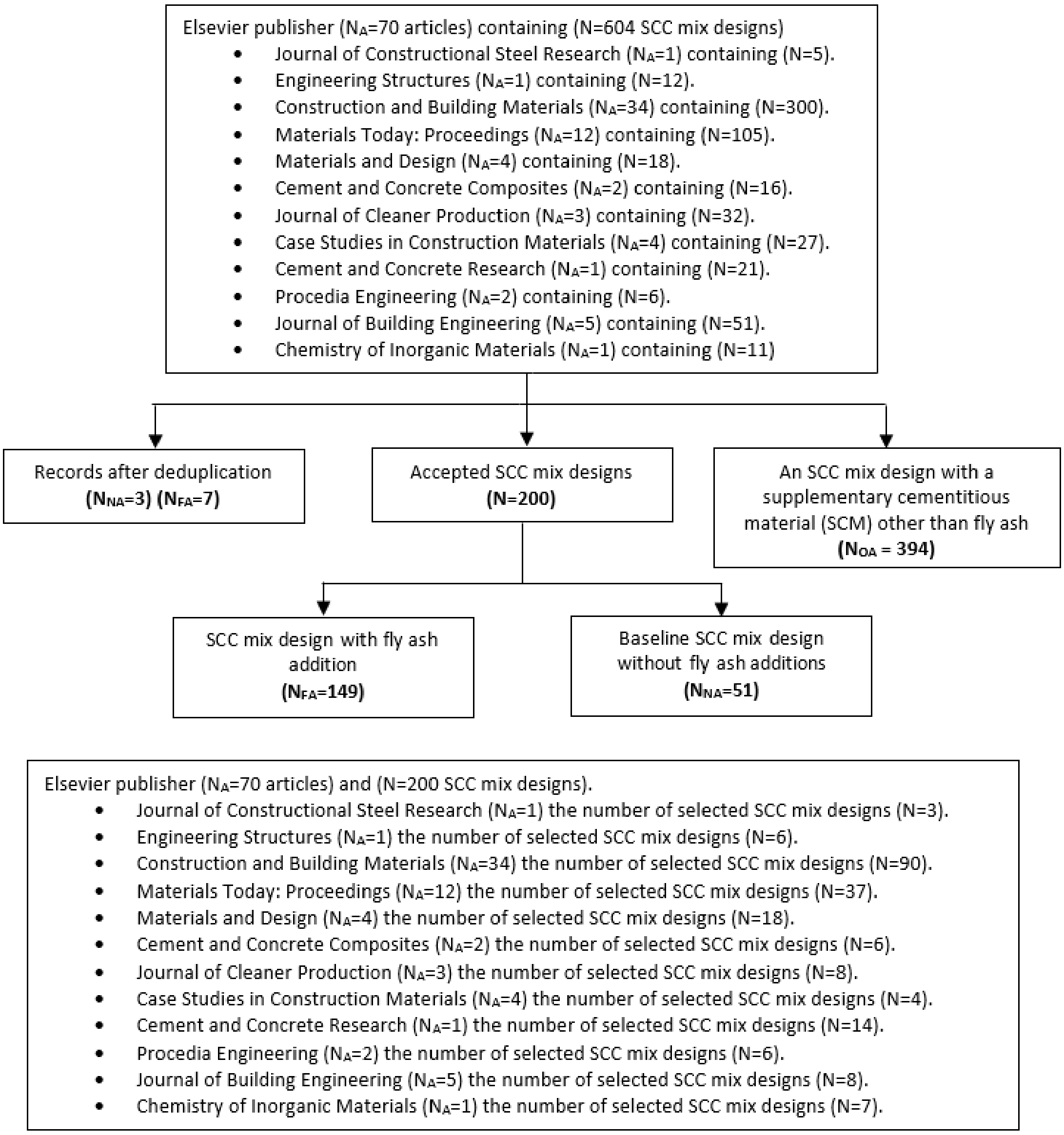

Fig. 2. Data retrieval, screening, eligibility, and inclusion sequences were used.

3. Literature review

In this study, we analyzed 70 research articles on self-compacting concrete (SCC) that encompassed 200 variations in SCC mix design. These articles were selected based on the availability of fresh-state results, either partially or completely. Among the 200 studied variations in SCC mix designs, we identified 51 formulations without any additional admixtures, which represented the baseline formulation. The remaining 149 variations of the SCC mix design involved varying percentages of fly ash relative to cement. However, it is pertinent to emphasize that the representation of gravel and sand grading curves is often omitted in the articles, for example (Elango et al., 2022; N. Li et al., 2020; Liu et al., 2023; Vinod Kumar & Narendra Kumar, 2022). The studies that included these curves in their analyses allowed us to verify the grading curves for detecting inert fines with diameters less than 80 µm. It is important to note that the research conducted by (Anjos et al., 2020; Gautam et al., 2022; Jiang & Zhang, 2022) highlighted the presence of fines in sand.

3.1. Self-compacting concrete without fly ash

In the first part of this study, we present the literature findings in Table 1, classifying the self-compacting concrete (SCC) mix designs in ascending order of water/cement ratio (W/C). These mix designs, without admixtures, were subjected to various tests, including Slump Flow, T500 flow time, V-funnel flow time, and L-box blocking ratio. Each study indicated the superplasticizer (SP) dosage used in the mix design, expressed as a percentage of the cement content, as well as different gravel/sand (G/S) ratios.

Table 1. Summary table of SCC rheological tests without the admixtures.

N°	Article	Ref	W/C	G/S	SP % / C	Slump flow [mm]	T500 [s]	V-Funnel	L-Box
1	N. Li and all.	(N. Li et al., 2020)	0.23	1.01	2.5	645	2		
2	N. Li and all.	(N. Li et al., 2020)	0.26	1.08	1.52	650	1		
3	P. R. Silva and J. De Brito	(Silva & Brito, 2015)	0.27	0.97	1	770		9.3	0.91
4	N. Li and all.	(N. Li et al., 2020)	0.28	1.12	1.2	655	1		
5	G. Sua-iam and B. Chatveera	(Sua-iam & Chatveera, 2021, 2022)	0.28	0.87	2	700	2.2	6.8	0.94
6	P. Promsawat and all.	(Promsawat et al., 2020)	0.28	0.88	2.2	750	3.4	11.59	0.8
7	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.84	0.40	680	3.90	7.50	0.85
8	F. A. Mustapha and all.	(Mustapha et al., 2021)	0.32	1.05	2.6	550		12	0.8
9	N. Li and all.	(N. Li et al., 2020)	0.33	1.15	0.80	650	1		
10	G. Erhan and all.	(Erhan et al., 2015)	0.33	1.00	0.60	735	3.7	9.4	0.98
11	M. Uysal and H. Tanyildizi	(Uysal & Tanyildizi, 2012)	0.33	0.90	1.60	690	4.25	14.44	0.82
12	R. Vilas and all.	(Vilas et al., 2022)	0.33	0.79	0.90	721	3.12	7.31	0.91
13	R. Choudhary and all.	(Choudhary et al., 2020)	0.33	0.74	1.40	710	2.7	10.4	0.966
14	T. Zhi and al.	(Zhi et al., 2020)	0.33	0.64	1.65	665	5.04	15	
15	Ram Vilas Meena and all.	(Vilas Meena et al., 2023)	0.33	0.82	1.12	705	4.02	8.90	0.85
16	N. Jahan and all.	(Jahan et al., 2023)	0.34	0.86	1.11	750	2.35	4.8	0.935
17	A. F. Bingöl and I. Tohumcu	(Bingöl & Tohumcu, 2013)	0.35	0.72	1.15	630	6.13	6.08	0.84

18	J. G. Jawahar and all.	(Jawahar et al., 2013)	0.35	0.72	1.15	630	6.13	6.08	0.84
19	E. Güneyisi and all.	(Güneyisi et al., 2012)	0.35	1.33	1.34	700	3.8	11.5	0.62
20	N. Puthipad and all.	(Puthipad et al., 2016)	0.35	0.86	1.90	640		10.8	
21	N. Puthipad and all.	(Puthipad et al., 2016)	0.35	0.78	2.81	605		35.6	
22	H. Zhao and all.	(Zhao et al., 2015)	0.35	1.56	0.24	700			0.92
23	M. Abed and all.	(Abed et al., 2022)	0.35	1.20	0.3	698		6	
24	C. Dong and all.	(Dong et al., 2022)	0.35	0.97	1.01	755	4		
25	L. Gautam and all.	(Gautam et al., 2022)	0.36	0.71	0.9	700	4.15	8.32	0.96
26	S. Altoubat and all.	(Altoubat et al., 2017)	0.36	0.67	0.88	620	10		0.7
27	A. Jain and all.	(Jain, Choudhary, et al., 2022a)	0.37	0.72	0.37	745	2.25	9.05	0.88
28	R. Faisal and all.	(Faisal et al., 2022)	0.37	1.08	0.81	678	4.5	7.5	0.85
29	A. Jain and all.	(Jain et al., 2020)	0.37	0.94	1.35	700	4	8	0.94
30	Abhishek Jain and all.	(Jain, Chaudhary, et al., 2022)	0.37	0.72	0.48	750			
31	N, Karthiga and all.	(Karthiga @ Shenbagam et al., 2023)	0.37	0.94	1.35	735	2.50	6.50	0.93
32	R. Bani Ardalan and all.	(Bani Ardalan et al., 2017)	0.38	0.54	0.45	650		5	
33	R. Chinthakunta and all.	(Chinthakunta et al., 2021)	0.38	1.22	0.45	550			
34	M. Damma and all.	(Damma et al., 2021)	0.38	1.22	0.45	550			
35	N. Pathak and R. Siddique	(Pathak & Siddique, 2012b), (Pathak & Siddique, 2012a)	0.38	1.06	2	620 ; 627			
36	P. Ricardo and all.	(Ricardo et al., 2019)	0.38	1.05	1.9	705	6	19	0.87
37	O. Boukendakdji and all.	(Boukendakdji et al., 2012)	0.40	0.97	1.60	630	1.25	7	
38	O. Boukendakdji and all.	(Boukendakdji et al., 2012)	0.40	0.97	1.80	500	1.4	10	
39	M. Sharbaf and all.	(Sharbaf et al., 2022)	0.40	0.75	0.55	673	2.6		0.78
40	M. A. S. Anjos and all.	(Anjos et al., 2020)	0.40	1.01	1.48	625	1.67	4.6	0.75
41	A. Zolghadri and all.	(Zolghadri et al., 2022)	0.42	0.44	0.8	650	1.8	2	
42	B. Selvarani and V. Preethi	(Selvarani & Preethi, 2021)	0.43	0.72	1.20	720	3.5	8.5	0.88
43	A. Singh and all.	(A. Singh et al., 2022, 2023)	0.43	0.79	0.50	580	5.5	12.5	0.9
44	E. Güneyisi and M. Gesog	(Güneyisi & Gesog, 2009)	0.44	1.05	0.40	670	1.0	3.2	0.706
45	M. R. Md Zain and all.	(Md Zain et al., 2021)	0.45	0.85	0.63	630	4.0		0.98
46	Barbara Klemczak and all.	(Klemczak et al., 2023)	0.45	1.41	1.28	680			
47	A. Zolghadri and all.	(Zolghadri et al., 2022)	0.46	0.44	0.75	630	0.8	2.5	
48	M. Monaliza and all.	(Monaliza et al., 2022)	0.46	1.12	0.2	670	1.96	4.38	0.9
49	H. A. A. Diniz and all.	(Diniz et al., 2022)	0.50	1.00	0.61	785	4.0	14	
50	G. Fahim and all.	(Fahim et al., 2021)	0.52	0.90	0.96	665	3.75	0.84	
51	M. A. S. Anjos and all.	(Anjos et al., 2020)	0.60	0.82	0.90	500	4.2		

3.2. Self-compacting concrete with fly ash

In the second part of the study, we present the literature findings by classifying the self-compacting concrete (SCC) mix designs in ascending order of the Equivalent Water/Binder (W/B) ratio. Here, B refers to the total amount of powder material, including cement and supplementary cementitious materials (SCMs) such as fly ash. These mix designs were subjected to various tests, including Slump Flow, T500 flow time, V-funnel flow time, and L-box blocking ratio. Each study indicated the superplasticizer (SP) dosage used in the mix design, expressed as a percentage of the equivalent binder content, and various gravel/sand (G/S) ratios.

Table 2. Summary table of SCC rheological tests with the admixtures.

N°	Article	Ref	W/B	W/C	G/S	SP % / B	SP % / C	Slump flow [mm]	T500 [s]	V-Funnel	L-Box
1	S. A. Kristiawan and M. T. M. Aditya	(Kristiawan & Aditya, 2015), (Kristiawan & Agung P Nugroho, 2017)	0.18	0.52	1	1.14	3.26	760	3.27	16	0.85
2	S. A. Kristiawan and M. T. M. Aditya	(Kristiawan & Aditya, 2015), (Kristiawan & Agung P Nugroho, 2017)	0.22	0.49	1	1.14	2.53	740	3.57	22.98	0.9
3	S. A. Kristiawan and Agung P Nugroho	(Kristiawan & Aditya, 2015), (Kristiawan & Agung P Nugroho, 2017)	0.22	0.34	1	1.14	1.75	745	3.7	24.73	0.73
4	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.23	0.28	0.86	1.87	2.25	720	3	9	0.9
5	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.23	0.28	0.86	1.87	2.25	690	4	9	0.9
6	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.24	0.29	0.86	1.87	2.25	690	3	8	0.8
7	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.25	0.30	0.85	1.87	2.25	720	3	10	0.9
8	A. Meena and all.	(Meena et al., 2023)	0.25	0.49	0.80	0.85	1.70	730	3.8	8.3	0.95
9	Y. Huang and all.	(Huang et al., 2022)	0.27	0.39	1.03	1.02	1.45	660	1		
10	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.27	0.32	0.86	1.87	2.25	750	4	11	0.8
11	N. Li and all.	(N. Li et al., 2020)	0.28	0.38	1.02	0.81	1.10	600	1		
12	G. Vinod Kumar and B. Narendra Kumar	(Vinod Kumar & Narendra Kumar, 2022)	0.28	0.31	1.08	0.80	0.80	780		7	0.92
13	Z. Ge and all.	(Ge et al., 2021)	0.28	0.47	1.06	0.80	1.33	745.2	3.75		0.82
14	P. R. Silva and J. De Brito	(Silva & Brito, 2015)	0.28	0.36	0.95	0.76	0.99	680		7.3	0.84
15	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.29	0.35	0.87	1.88	2.25	720	3	10	0.9
16	P. Dinakar and all.	(Dinakar et al., 2013)	0.30	0.33	1.08	1.20	1.33	620	6	28.19	0.77
17	P. Dinakar and all.	(Dinakar et al., 2013)	0.30	0.43	1.09	1.30	1.86	685	5	16	0.8
18	P. Dinakar and all.	(Dinakar et al., 2013)	0.30	0.60	1.09	1.30	2.60	705	5	20.39	0.93
19	P. Dinakar and all.	(Dinakar et al., 2013)	0.30	1.00	1.08	1.60	5.33	670	7	28.16	0.83
20	M. S. Ashtiani and all.	(Ashtiani et al., 2013)	0.30	0.43	1.01	0.65	0.65	750	4.2	8	0.92
21	P. R. Silva and J. De Brito	(Silva & Brito, 2015)	0.30	0.62	0.94	0.66	1.38	670		8.4	0.81
22	P. R. Silva and J. De Brito	(Silva & Brito, 2015)	0.30	0.82	0.94	0.51	1.38	660		8.6	0.79

23	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.32	0.84	0.38	0.40	670	4	7.92	0.85
24	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.33	0.84	0.36	0.40	650	3.6	8.10	0.87
25	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.35	0.84	0.34	0.40	665	4.5	6.84	0.89
26	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.38	0.84	0.32	0.40	672.5	3	4.30	0.90
27	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.40	0.84	0.30	0.40	680	4.4	4.82	0.91
28	Madasu Durga Rao and all.	(Rao et al., 2023)	0.30	0.43	0.84	0.28	0.40	690	3.2	5.50	0.93
29	K. S. Elango and all.	(Elango et al., 2022)	0.31	0.40	0.94	0.70	0.7	695		9.7	1.1
30	B. Sukumar	(Sukumar, 2008)	0.31	0.34	0.92	0.64	0.7	742	2	6	0.95
31	T. Zhi and all.	(Zhi et al., 2020)	0.31	0.44	0.64	1.65	2.36	700	4.38	14	
32	T. Zhi and all.	(Zhi et al., 2020)	0.31	0.52	0.64	1.65	2.75	710	4.35	13	
33	T. Zhi and all.	(Zhi et al., 2020)	0.31	0.62	0.64	1.65	3.30	730	1.82	13	
34	Y. Huang and all.	(Huang et al., 2022)	0.32	0.46	1.03	0.77	1.1	670	1		
35	Y. Jiang and S. Zhang	(Jiang & Zhang, 2022)	0.32	0.45	1.03	1.55	2.21	690	4.1		
36	F. A. Mustapha and all.	(Mustapha et al., 2021)	0.32	0.43	1.14	2.00	2.00	640		11.6	0.84
37	B. Sukumar	(Sukumar, 2008)	0.32	0.44	0.92	0.37	0.5	773	1.5	5	0.96
38	B. Sukumar	(Sukumar, 2008)	0.32	0.38	0.92	0.50	0.6	766	1.5	6	0.95
39	N. Puthipad and all.	(Puthipad et al., 2016)	0.32	0.54	0.78	0.96	0.96	610		17	
40	N. Puthipad and all.	(Puthipad et al., 2016)	0.32	0.80	0.78	0.80	0.80	600		11.1	
41	R. H. Faraj and all.	(Faraj et al., 2021)	0.32	0.40	1.00	1.35	1.68	750	3.8	19	0.89
42	M. Uysal and H. Tanyildizi	(Uysal & Tanyildizi, 2012)	0.33	0.39	0.88	1.55	1.83	710	3.13	9.34	0.908
43	M. Uysal and H. Tanyildizi	(Uysal & Tanyildizi, 2012)	0.33	0.44	0.85	1.50	2.00	740	2.22	11.58	0.924
44	M. Uysal and H. Tanyildizi	(Uysal & Tanyildizi, 2012)	0.33	0.51	0.85	1.45	2.24	740	2.18	16.97	0.905
45	M. Harihanandh and all.	(Harihanandh et al., 2021)	0.33	0.40	0.86	1.88	2.26	700	3	9	0.9
46	B. Sukumar	(Sukumar, 2008)	0.33	0.54	0.92	0.24	0.4	786	1	5	0.99
47	G. Erhan and all.	(Erhan et al., 2015)	0.33	0.44	1.00	0.50	0.67	760	2.7	8.7	1
48	G. Erhan and all.	(Erhan et al., 2015)	0.33	0.66	1.00	0.40	0.80	770	2.1	8.1	1
49	G. Erhan and all.	(Erhan et al., 2015)	0.33	1.32	1.00	0.30	1.20	790	1.4	7.3	1
50	N. Puthipad and all.	(Puthipad et al., 2016, 2017)	0.33	0.55	0.86	0.82	0.82	685		6	
51	N. Puthipad and all.	(Puthipad et al., 2016, 2017)	0.33	0.83	0.86	0.65	0.65	620		11.1	
52	N. Puthipad and all.	(Puthipad et al., 2016, 2017)	0.33	0.50	0.86	0.80	0.8	630		9.83	
53	M. Nuruzzaman and all.	(Nuruzzaman et al., 2022)	0.34	0.44	0.77	1.74	2.26	785		6	0.98
54	B. Sukumar	(Sukumar, 2008)	0.34	0.71	0.92	0.19	0.4	793	1	4	1
55	S. Yang and all.	(Yang et al., 2021)	0.34	0.45	1.00	0.80	1.08	560		7.01	
56	S. Yang and all.	(Yang et al., 2021)	0.34	0.45	1.00	0.90	1.21	640		6.3	
57	S. Yang and all.	(Yang et al., 2021)	0.34	0.45	1.00	1.00	1.35	700		5.35	
58	M. A. S. Anjos and all.	(Anjos et al., 2020)	0.34	0.85	1.01	1.80	4.50	700	1.85	4.8	0.86
59	N. Li and all.	(N. Li et al., 2020)	0.35	0.56	1.10	0.25	0.41	670	1		
60	A. F. Bingöl and I. Tohumcu	(Bingöl & Tohumcu, 2013)	0.35	0.47	0.72	1.50	2.00	660	7.7	6.95	0.85
61	A. F. Bingöl and I. Tohumcu	(Bingöl & Tohumcu, 2013)	0.35	0.58	0.72	1.50	2.50	680	6.8	6.2	0.88
62	A. F. Bingöl and I. Tohumcu	(Bingöl & Tohumcu, 2013)	0.35	0.78	0.72	1.50	3.33	700	7.6		
63	J. G. Jawahar and all.	(Jawahar et al., 2013)	0.35	0.47	0.72	1.50	2.00	660	7.7	6.95	0.85
64	J. G. Jawahar and all.	(Jawahar et al., 2013)	0.35	0.58	0.72	1.50	2.50	680	6.8	6.3	0.88
65	J. G. Jawahar and all.	(Jawahar et al., 2013)	0.35	0.78	0.72	1.50	3.33	700	7.6	7	0.91
66	E. Güneyisi and all.	(Güneyisi et al., 2012)	0.35	0.50	1.33	0.87	1.24	720	2.9	12	0.92

67	E. Güneyisi and all.	(Güneyisi et al., 2019)	0.35	0.47	1.00	1.00	1.33	700	3.7	11.5	0.94
68	G. Vinod Kumar	(Vinod Kumar & Narendra Kumar, 2022)	0.35	0.44	1.56	0.19	0.24	725			0.95
69	G. Vinod Kumar	(Vinod Kumar & Narendra Kumar, 2022)	0.35	0.50	1.56	0.17	0.24	750			0.96
70	G. Vinod Kumar	(Vinod Kumar & Narendra Kumar, 2022)	0.35	0.58	1.56	0.14	0.24	760			0.98
71	M. Abed and M. Ju	(Abed et al., 2022)	0.35	0.41	1.20	0.60	0.4	680		5.8	
72	M. Abed and M. Ju	(Abed et al., 2022)	0.35	0.50	1.20	0.80	0.6	675		6.4	
73	M. A. S. Anjos and all.	(Anjos et al., 2020)	0.35	0.88	0.89	3.10	7.75	750	1.83	5.85	0.94
74	J. G. Jawahar and all.	(Jawahar et al., 2013)	0.36	0.55	0.85	0.90	1.39	696	3.12	6.23	0.81
75	S. Altoubat and all.	(Altoubat et al., 2017)	0.36	0.45	0.67	1.44	1.81	720	5		0.85
76	S. Altoubat and all.	(Altoubat et al., 2017)	0.36	0.55	0.68	1.22	1.88	600	6		0.8
77	S. Altoubat and all.	(Altoubat et al., 2017)	0.36	0.72	0.70	1.22	2.44	680	5		0.95
78	Abhishek Jain	(Jain, Chaudhary, et al., 2022)	0.37	0.53	0.72	0.15	0.21	750			
79	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.46	0.94	0.80	1.00	730	3.30	8.50	0.91
80	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.46	1.18	0.72	0.90	645	5.50	10.80	0.81
81	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.46	1.57	0.88	1.10	575	6.30	12.40	0.72
82	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.46	2.35	1.20	1.50	555	7.20	12.10	0.65
83	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.46	4.69	1.52	1.90	540	7.40	11.80	0.53
84	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.53	0.94	0.56	0.80	720	3.50	8.90	0.88
85	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.53	1.18	0.42	0.60	595	5.40	11.40	0.76
86	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.53	1.57	0.56	0.80	565	6.40	12.90	0.68
87	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.53	2.35	0.84	1.20	550	6.90	12.70	0.61
88	N, Karthiga	(Karthiga @ Shenbagam et al., 2023)	0.37	0.53	4.69	1.19	1.70	540	7.10	12.30	0.50
89	A. Jain and all.	(Jain, Choudhary, et al., 2022b)	0.37	0.53	0.72	0.15	0.21	770	1.54	5.91	0.98
90	A. Jain and all.	(Jain et al., 2020)	0.37	0.46	0.94	0.76	0.95	675	1	11	0.94
91	A. Jain and all.	(Jain et al., 2020)	0.37	0.53	0.94	0.52	0.75	685	0.7	16	0.97
92	S. Yang and all.	(Yang et al., 2021)	0.37	0.50	1.00	0.80	1.08	700		4.19	
93	S. Yang and all.	(Yang et al., 2021)	0.37	0.50	1.00	0.90	1.21	715		4.3	
94	S. Yang and all.	(Yang et al., 2021)	0.37	0.50	1.00	1.00	1.35	718		4.7	
95	Y. Huang and all.	(Huang et al., 2022)	0.38	0.54	1.03	0.42	0.60	672	1		
96	R. Bani Ardalan et all.	(Bani Ardalan et al., 2017)	0.38	0.42	0.56	0.43	0.43	650		5	
97	R. Bani Ardalan et all.	(Bani Ardalan et al., 2017)	0.38	0.48	0.56	0.40	0.40	650		5	
98	R. Bani Ardalan et all.	(Bani Ardalan et al., 2017)	0.38	0.55	0.56	0.38	0.38	650		7	
99	R. Bani Ardalan et all.	(Bani Ardalan et al., 2017)	0.38	0.64	0.55	0.35	0.35	650		7	
100	R. Bani Ardalan et all.	(Bani Ardalan et al., 2017)	0.38	0.76	0.56	0.25	0.25	650		8	
101	S. Barbhuiya	(Barbhuiya, 2011)	0.38	0.76	0.67	0.30	0.59	645		5.9	0.76
102	N. Pathak and R. Siddique	(Pathak & Siddique, 2012b)	0.38	0.40	1.06	1.72	1.82	634			

103	N. Pathak and R. Siddique	(Pathak & Siddique, 2012b)	0.40	0.43	1.02	1.67	1.8	652			
104	M. Sharbaf and all.	(Sharbaf et al., 2022)	0.40	0.47	0.75	0.49	0.12	667	2.2	0.91	12
105	M. Sharbaf and all.	(Sharbaf et al., 2022)	0.40	0.52	0.75	0.42	0.11	673	2	0.93	12
106	M. Sharbaf and all.	(Sharbaf et al., 2022)	0.40	0.57	0.75	0.40	0.12	673	1.9	0.93	12
107	M. Sharbaf and all.	(Sharbaf et al., 2022)	0.40	0.64	0.75	0.35	0.12	641	1.8	0.91	25
108	R. Siddique and G. Kaur	(Siddique & Kaur, 2016)	0.41	0.46	0.65	1.20	1.2	720		7	0.98
109	R. Siddique	(Siddique, 2011)	0.41	0.49	0.65	1.95	1.95	673.3	4.5	7.5	0.89
110	P. Ricardo and all.	(Ricardo et al., 2019)	0.41	0.63	1.09	0.65	1.9	700	3	9	0.89
111	P. Ricardo and all.	(Ricardo et al., 2019)	0.41	0.76	1.08	0.43	1.2	675	3	13	0.96
112	S. Yang and all.	(Yang et al., 2021)	0.41	0.55	1.00	0.80	1.08	730		4.22	
113	S. Yang and all.	(Yang et al., 2021)	0.41	0.55	1.00	0.90	1.21	710		4.63	
114	S. Yang and all.	(Yang et al., 2021)	0.41	0.55	1.00	1.00	1.35	700		4.46	
115	R. Siddique	(Siddique, 2011)	0.42	0.50	0.65	2.00	2	673	4.5	7.5	0.89
116	E. M. Mervin et all.	(Mervin et al., 2021)	0.42	0.61	0.83	0.17	0.25	660	2.9	10.8	
117	R. Siddique	(Siddique, 2013)	0.42	0.52	0.65	2.00	2	690	3	4.5	0.95
118	R. Siddique	(Siddique, 2013)	0.42	0.56	0.65	1.80	1.8	603.3	4.4	5.2	0.85
119	N. Pathak	(Pathak & Siddique, 2012b)	0.42	0.46	1.00	1.56	1.72	678			
120	P. Ricardo and all.	(Ricardo et al., 2019)	0.42	0.63	1.10	0.69	2	685	5	14	0.92
121	P. Ricardo and all.	(Ricardo et al., 2019)	0.42	0.63	1.05	0.40	1.1	698	2	10	0.89
122	P. Ricardo and all.	(Ricardo et al., 2019)	0.42	0.95	1.10	0.42	1.2	695	3	14	0.9
123	A. Singh et all.	(A. Singh et al., 2022)	0.43	0.45	0.79	0.80	0.84	600	5.3	12.3	0.89
124	A. Singh et all.	(A. Singh et al., 2022)	0.43	0.48	0.79	0.80	0.89	625	5	12.2	0.85
125	A. Singh et all.	(A. Singh et al., 2022)	0.43	0.51	0.79	0.80	0.94	630	4.7	12.1	0.84
126	A. Singh et all.	(A. Singh et al., 2022), (A. Singh et al., 2023)	0.43	0.54	0.79	0.80	1.00	645 ; 648	4.1. 7.1	12	0.83
127	A. Singh et all.	(A. Singh et al., 2022)	0.43	0.57	0.79	0.80	1.07	665	4	11.3	0.82
128	A. Singh et all.	(A. Singh et al., 2022)	0.43	0.61	0.79	0.80	1.14	670	3.4	11.1	0.81
129	A. Singh et all.	(A. Singh et al., 2022)	0.43	0.66	0.79	0.80	1.23	705	3	11	0.8
130	R. Siddique	(Siddique, 2011)	0.43	0.61	0.65	1.80	1.8	673.3	3	6.1	0.95
131	R. Siddique	(Siddique, 2011)	0.44	0.68	0.65	1.80	1.8	633.3	4	10	0.92
132	E. Güneyisi and M. Gesog	(Güneyisi & Gesog, 2009)	0.44	0.55	1.05	0.71	0.89	675	2	10.4	0.706
133	E. Güneyisi and M. Gesog	(Güneyisi & Gesog, 2009)	0.44	0.73	1.05	0.64	1.07	730	2	6	0.8
134	E. Güneyisi and M. Gesog	(Güneyisi & Gesog, 2009)	0.44	1.10	1.05	0.67	1.67	720	1	4	0.95
135	M. Sonebi	(Sonebi, 2004)	0.45	0.92	1.06	0.8	1.64	555		4.87	0.2
136	Barbara Klemczak	(Klemczak et al., 2023)	0.54	1.13	1.41	1.55	3.21	710			
137	M. Sonebi	(Sonebi, 2004)	0.55	1.12	1.75	0.5	1.02	705		2.88	0.58
138	M. Sonebi	(Sonebi, 2004)	0.55	0.90	1.13	0.5	0.82	625		2.13	0.43
139	M. Sonebi	(Sonebi, 2004)	0.55	0.90	1.13	0.5	0.82	605		1.95	0.31
140	M. Sonebi	(Sonebi, 2004)	0.55	0.90	1.13	0.5	0.82	625		2.33	0.45
141	M. Sonebi	(Sonebi, 2004)	0.55	0.90	1.13	0.5	0.82	605		2.27	0.32
142	M. Sonebi	(Sonebi, 2004)	0.55	0.83	1.41	0.5	0.75	697		4.18	0.89
143	M. Sonebi	(Sonebi, 2004)	0.55	0.90	1.13	0.5	0.82	600		2.19	0.41
144	M. Sonebi	(Sonebi, 2004)	0.55	0.90	1.12	1	1.64	790		5.43	0.89
145	M. Sonebi	(Sonebi, 2004)	0.65	0.96	0.92	0.8	1.18	575		3.03	0.45
146	M. Sonebi	(Sonebi, 2004)	0.65	1.14	2.27	0.8	1.41	785		1.31	0.89
147	M. Sonebi	(Sonebi, 2004)	0.65	0.87	1.18	0.2	0.27	623		3.89	0.7
148	M. Sonebi	(Sonebi, 2004)	0.65	1.33	1.49	0.2	0.41	737		2.69	0.67
149	M. Sonebi	(Sonebi, 2004)	0.72	1.18	1.48	0.5	0.82	880		2.53	0.97

4. Analysis of results

The admixture dosage, typically ranging from 0.1% to 3% of the cement content, can vary by up to 7.75%, according to other studies (Anjos et al., 2020; Dinakar et al., 2013; Klemczak et al., 2023). The specifications regarding the nature of admixtures are often neglected and have not been consistently reported in the literature. However, the performance results were highly dependent on the chemical admixtures (Hajime & Masahiro, 2003).

Figure 3 illustrates the results of various tests in three dimensions: the slump flow test, T500 flow time, L-box blocking ratio, and V-funnel flow time, as a function of variations in water and superplasticizer dosage with and without fly ash.

The analysis of results from various researchers, as illustrated in Figure 3, reveals a notable scatter in the experimental data. This indicates that Self-Compacting Concrete (SCC) formulations with or without fly ash exhibit variable responses to different combinations of superplasticizers and water content. While the substitution of cement with fly ash did not significantly alter the rheological behavior of the concrete across the various tests shown in Figure 3, it facilitated cost reductions and enhanced granular packing density. At first glance, this dispersion of results obscures a clear interpretation of the admixture's impact on SCC performance. However, these observations suggest that the coefficient associated with the admixture plays a critical role in governing the rheological behavior of the concrete.

Moreover, the impact of water on concrete appears to follow a linear relationship with its rheology: an increase in water content leads to an increase in SCC fluidity. However, this is not necessarily the case for admixture. According to the literature, a small or large admixture dosage can produce a similar rheology, as shown in Figure 3.

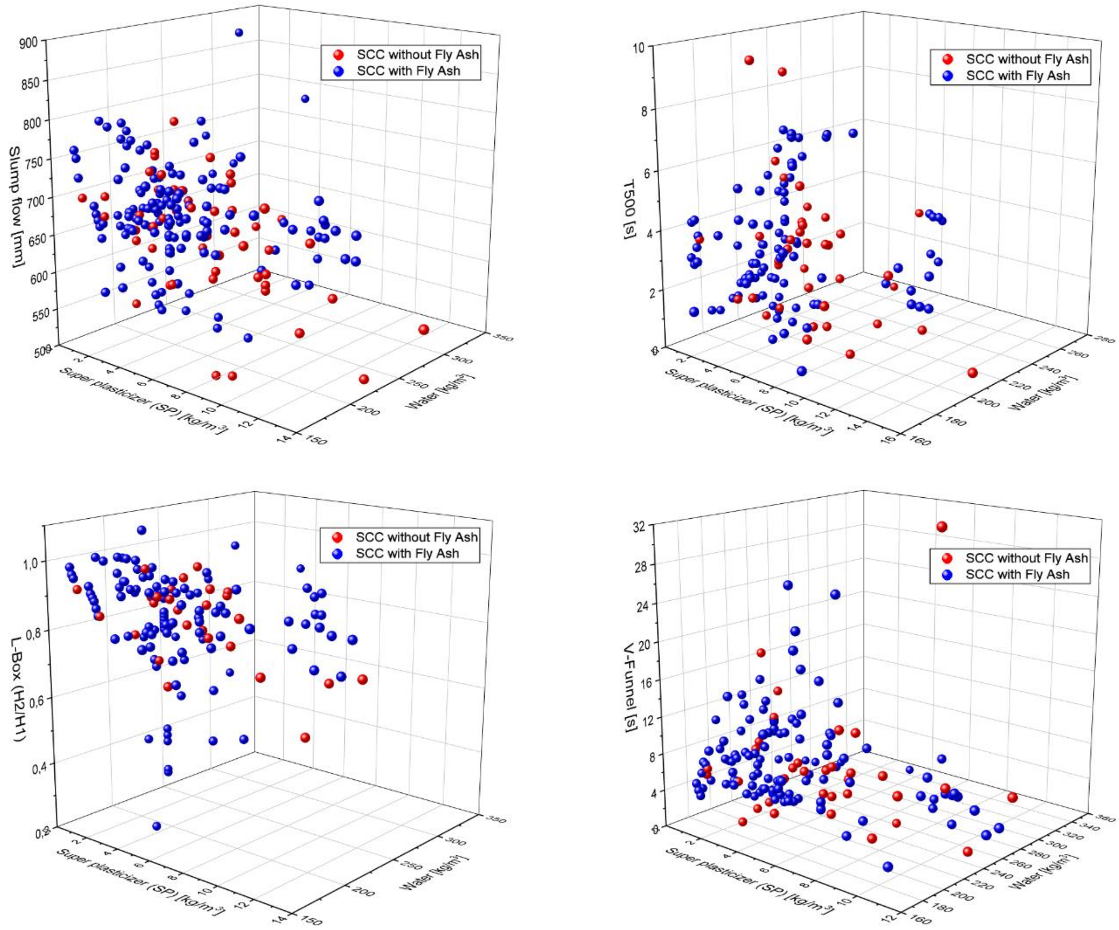

Fig. 3. Rheological test results as a function of water and superplasticizer with and without fly ash.

Figure 4 presents the impact of water and admixture dosage on the rheological properties of self-compacting concrete (SCC), as per the EFNARC specifications (EFNARC, 2002, 2005). This was demonstrated through various tests, including the slump flow test, T500 flow time, L-box blocking ratio, and V-funnel flow time. This depiction facilitates the identification of the most frequently studied classes based on the results obtained by the researchers. In the slump flow test, Figure 4 indicates that five classes were distinguished according to the EFNARC criteria (EFNARC, 2002, 2005), with 95.65% of the data points falling within classes SF1, SF2, and SF3. Specifically, class SF2, which has been extensively studied by various researchers, comprises 59.90% of the data points, whereas SF1 and SF3 account for 27.05% and 8.70%, respectively, in accordance with the EFNARC criteria (EFNARC, 2002, 2005). Class SF3 has been less explored by researchers. The unclassified results (N-C), with a slump flow exceeding class SF3, constituted 0.48%, whereas those below class SF1 represented 3.86%. In the T500 test, two classes were identified based on the EFNARC criteria (EFNARC, 2002, 2005). The findings revealed that 24.82% were classified as class VS1 for a flow time of less than or equal to 2 s. Conversely, class VS2, with results exceeding 2 s, accounted for 75.18% of the observations in this synthesis, making it the most studied class. In the V-funnel test, unclassified results (N-C) with a flow time exceeding 25 s, according to the EFNARC criteria (EFNARC, 2002, 2005), represented 1.84% of the observations. In contrast, 60.74% of the observations fell within class VF2, with a flow time between 9 and 25 s, whereas 37.42% fell within class VF1, with a flow time of less than or equal to 8 s, making it the most studied class by researchers. Regarding the L-box test, 24.83% of the observations were not classified according to the EFNARC criteria (EFNARC, 2002, 2005), indicating an H1/H2 ratio of less than 0.80. In contrast, 75.17% of the observations were classified as PA1 or PA2 based on the number of bars.

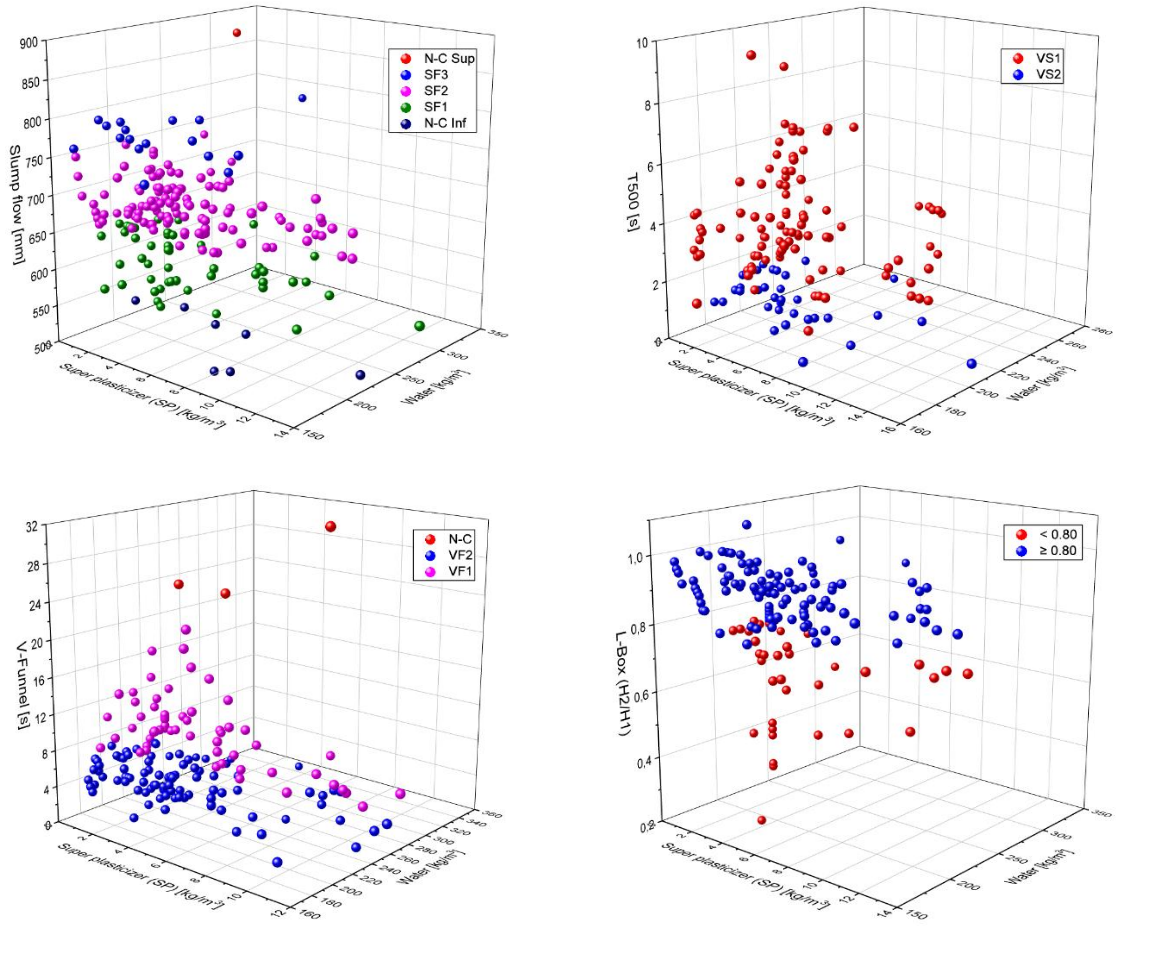

Fig. 4. Different tests were performed as a function of water and superplasticizer according to the EFNARC (EFNARC, 2002, 2005) specifications.

Figure 5 shows the minimum and maximum outcomes of various experimental tests, including the slump flow test, T500 flow time, L-box blocking ratio, and V-funnel flow time, as a function of the admixture dosage, expressed in kg/m^3, based on literature data.

The admixture dosages were categorized into intervals with a step of 1, denoted as]A-B], where B > A and the value of A was excluded from the interval. The difference between B and A represents the admixture dosage (kg/m^3). The gap between the maximum and minimum values for the different tests generally remained stable, albeit notably.

This stability suggests consistency in the results, while highlighting significant variations attributable to the self-compacting concrete (SCC) mix design parameters, such as the water/cement ratio, superplasticizer dosage, and aggregate grading. For the slump flow test, the results ranged between 700 and 800 mm, with a positive peak in the]2-3] interval at 870 mm and a negative peak in the]15-16] interval at 560 mm. Furthermore, the maximum values exhibited stable behavior compared to the minimum values for different admixture dosages. Regarding the L-box test, a similar behavior to the slump flow test was observed, except for the changing values, where H1/H2 varied between 0.8 and 1, with a peak exceeding 1 in the]5-6] interval.

In contrast, the T500 and V-funnel tests, which were employed to determine viscosity, demonstrated behavior different from that of the previous tests. They exhibited a viscous relationship with nonlinear behavior characterized by multiple peaks, indicating that the admixture significantly influenced the rheological behavior of the concrete.

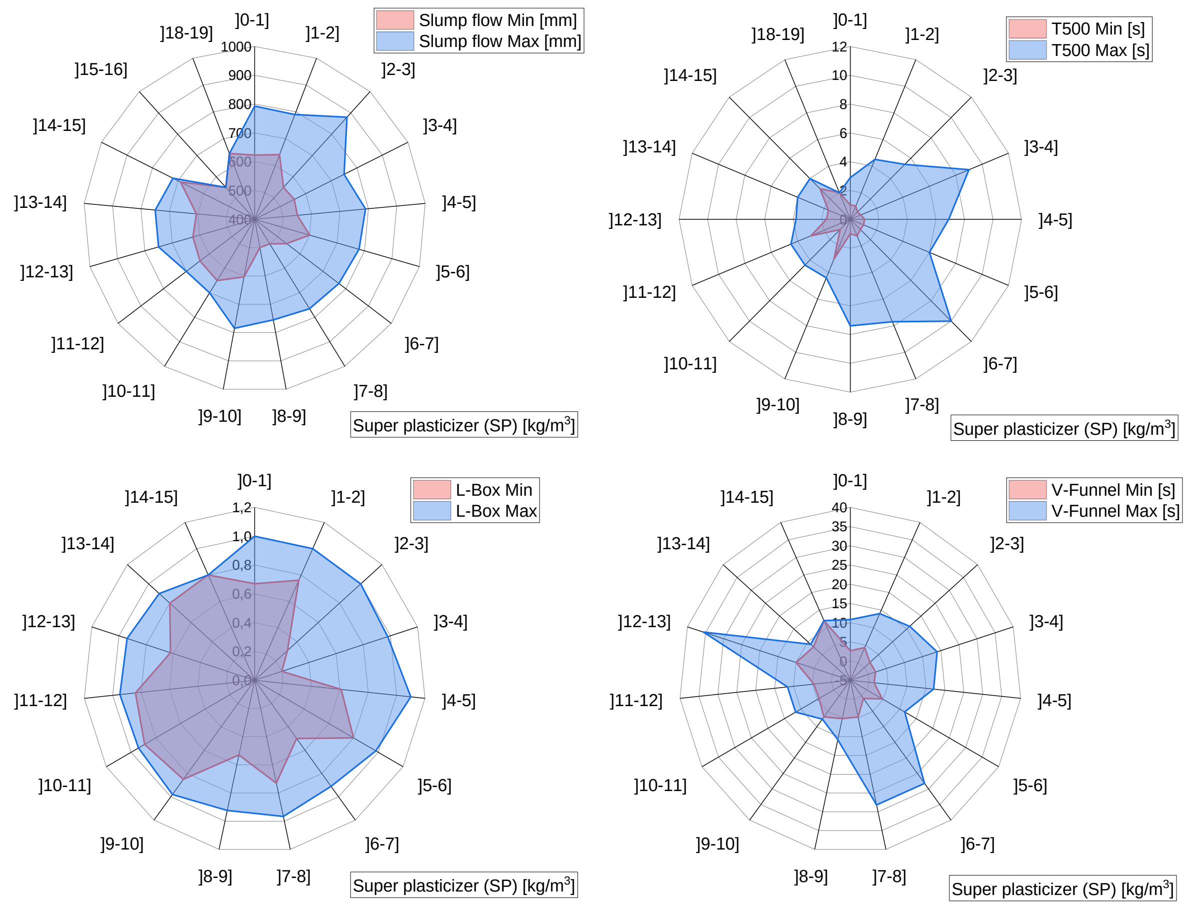

Fig. 5. Evolution of rheological test results as a function of admixture dosage (kg/m^3) – Analysis of maximum and minimum deviations.

Figure 6 illustrates the distribution of superplasticizer dosages (%) relative to cement based on their frequency of use by different researchers. These data, expressed as a percentage (%), were analyzed using Slump Flow, T500 flow time, V-funnel flow time, and L-box blocking ratio tests. The analysis of the curves highlighted three distinct peaks corresponding to the most commonly adopted dosages in the analysis of self-compacting concrete (SCC) rheology. A similar trend was observed for the four tests.

Three significant peaks in admixture percentage were noted, representing the most frequent dosages in the literature. The first peak was in the]0.75–1.00%] interval, with values of 15.45% (Slump Flow), 13.38% (T500 flow time), 29% (V-funnel flow time), and 17.24% (L-box blocking ratio). These results indicate the stabilization of the rheological properties of concrete. The second peak appeared in the]1.00–1.25%] interval, with values of 13.04% (Slump Flow), 12.67% (T500 flow time), 23% (V-funnel flow time), and 11.72% (L-box blocking ratio), reflecting an optimal balance between mixing fluidity and stability. Finally, the third peak, located in the]1.75%–2.00%] interval, showed a slight decrease in values with 12.56% (Slump Flow), 13.38% (T500 flow time), 19% (V-funnel flow time), and 13.10% (L-box blocking ratio), indicating a saturation effect where excess admixture no longer significantly improved the mix rheology.

Beyond this third peak, a progressive decrease was observed until the]3.00–3.25%] interval, followed by a slight increase in the]3.25–3.50%] interval, with values of 2.41% (Slump Flow), 3.52% (T500 flow time), 4% (V-funnel flow time), and 2.75% (L-box blocking ratio). This peak is associated with an increased risk of concrete segregation.

The analysis in Figure 6 highlights the importance of an optimized superplasticizer dosage, allowing for a balance between fluidity, stability, and flowability. Such control is essential to ensure the optimal placement of SCC adapted to the specific requirements of the intended applications.

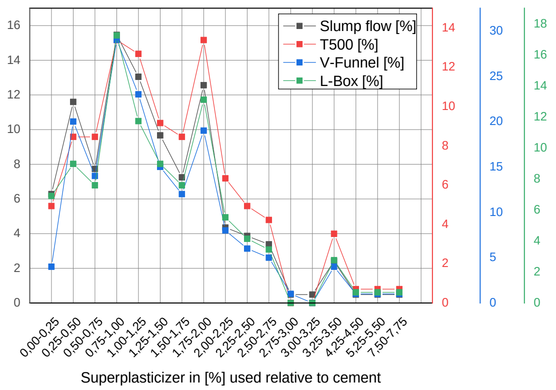

Fig. 6. Frequency of tests conducted by researchers [%] as a function of admixture dosage [%] relative to the cement.

Figure 7 presents the distribution of superplasticizer dosages (kg/m^3) as a function of their frequency of use by different researchers, expressed as a percentage (%), for various tests, including Slump Flow, T500 flow time, V-funnel flow time, and L-box blocking ratio. The results showed a similar trend for these four tests, with three distinct peaks representing the dosage ranges most commonly used by researchers, reflecting the direct influence of superplasticizer on the rheological properties of self-compacting concrete (SCC).

The first peak, observed in the]2-3] kg/m^3 interval, indicates that this dosage is among the most used, with variations of 15.46%, 11.35 %, 15.95 %, and 16.55% for Slump Flow, T500 flow time, V-funnel flow time, and 16.55% for L-box blocking ratio, respectively. This choice reflected a significant improvement in the fluidity and flowability of the mixture.

The second peak, located in the]3-4] kg/m^3 interval, represents another dosage range frequently employed by researchers, with percentages of 14.01%, 16.31%, 16.56%, and 14.48% for Slump Flow, T500 flow time, V-funnel flow time, and L-box blocking ratio, respectively. This range corresponds to further optimization of the rheological performance before the onset of potential instability.

The third peak, identified in the]7-8] kg/m^3 interval, indicates another concentration of studies using this dosage, with variations of 12.08%, 17.73 %, 6.75 %, and 15.17% for Slump Flow, T500 flow time, V-funnel flow time, and 15.17% for L-box blocking ratio, respectively. This peak suggests a progressive saturation of concrete with superplasticizer, reducing its effectiveness.

The correlation between the Slump Flow and V-funnel flow time tests highlights the relationship between the fluidity and viscosity of the mix, whereas the similarities between the T500 flow time and L-box blocking ratio suggest an interdependence between stability and flowability. These observations underscore the importance of determining an optimal dosage to ensure a balance between fluidity, stability, and workability while minimizing the risks of segregation or poor concrete compactness.

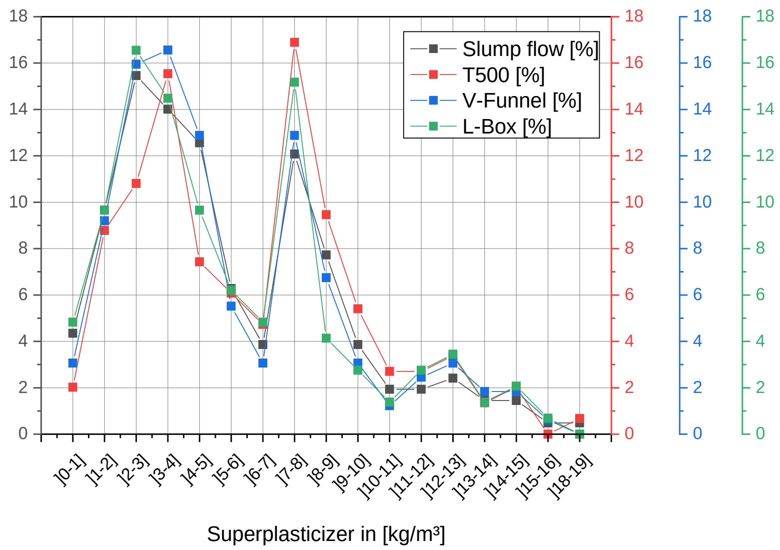

Fig. 7. Frequency of tests conducted by researchers [%] as a function of admixture dosage [kg/m^3].

Figure 8 shows the water content as a function of the superplasticizer dosage, expressed in kg/m^3, and the data points are color-coded according to the EFNARC specifications and criteria (EFNARC, 2002, 2005). The results from different authors show significant variations in rheological properties, despite the use of identical water and admixture dosages. This suggests that each admixture has its own activity index, determined by its specific chemical composition and solid content, which represents the amount of raw material diluted in water.

Thus, assuming that there is an equivalent water content for different combinations of water and admixture dosages, similar rheological results are obtained according to Equation 1. The equivalent water content was calculated using the following formula:

$$W_{equivalent} = (K \times A_d) + W \quad (1)$$

Where W is the water content used in the concrete (kg/m^3), The coefficient K, which is specific to each admixture (superplasticizer), depends on several parameters: its molecular structure, its solid content, and the chemical and physical interactions occurring between the cement and the admixture molecules. Ad represents the dosage of the admixture incorporated into the concrete, expressed in (kg/m^3).

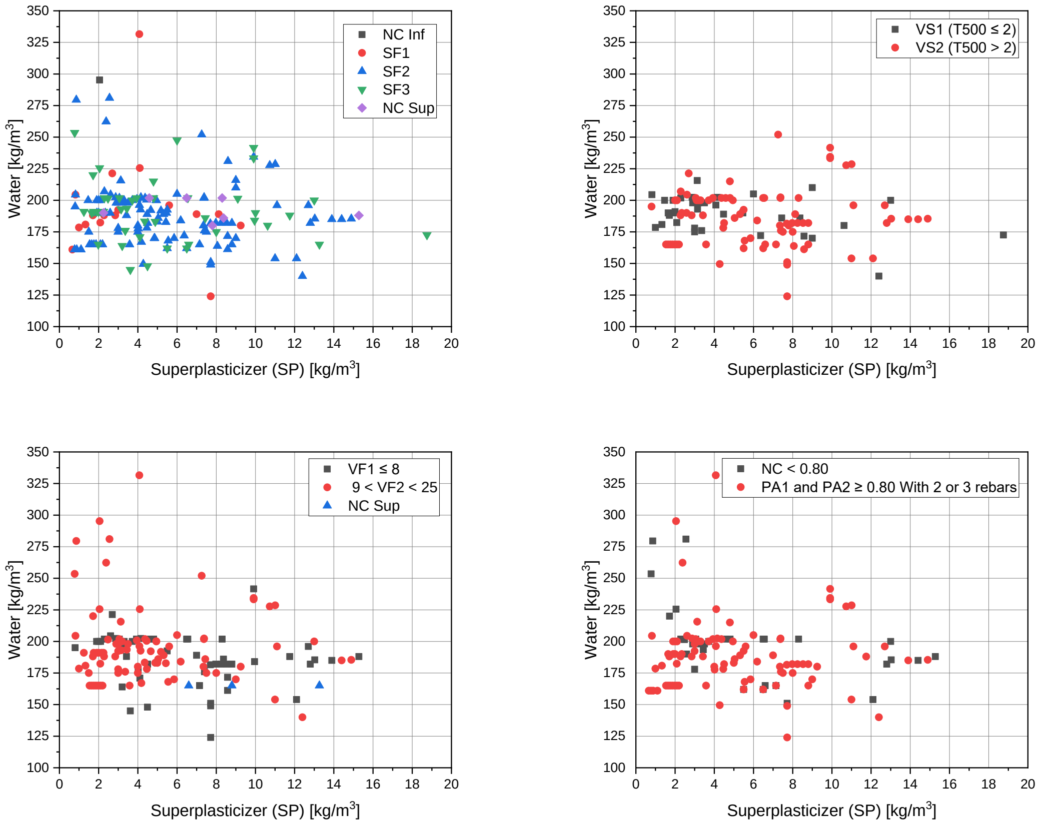

Fig. 8. Water content versus superplasticizer dosage for different tests.

Equation 1 represents the classical equation for calculating the admixture dosage in kg/m^3 as a function of the cement dosage in kg/m^3 and admixture percentage.

Admixture manufacturers generally indicate the recommended dosage on the product data sheet. Adhering to this dosage is important for obtaining adequate results. Furthermore, the admixture dosage may vary depending on concrete characteristics, such as cement composition, aggregate grading, and water content.

The admixture weight, expressed in kilograms per cubic meter, was calculated as a percentage relative to the equivalent binder weight, also in kilograms per cubic meter.

$$SP[kg/m^3] = C \times SP[\%] \quad (2)$$

Where C represents the cement dosage [kg/m^3], SP is the percentage [%] mentioned on the data sheet, generally between 1 and 3% of the cement dosage, and Ad is the admixture dosage [kg/m^3].

In the literature, admixture dosage is mentioned either as a percentage [%] or in kilograms [kg]. Using Equation 2, we calculated the admixture dosage in kg/m^3 from the percentage cited by the author as a function of the cement or powder dosage used, that is, cement plus supplementary cementitious materials (SCMs). Similarly, we calculated the admixture percentage based on the cement and admixture dosages in kg/m^3, allowing us to deduce the cement-to-admixture ratio using Equation 2.

Figure 9 shows the admixture dosage in kg/m^3 as a function of the admixture percentage calculated relative to the equivalent binder, obtained from the literature results using Equation 3. We obtained a trend curve with a coefficient of determination R^2 of 89.08%.

$$SP[kg/m^3] = -0{,}12 + 5{,}47 \times SP[\%] \text{ With } R^2 = 89.08\ \% \quad (3)$$

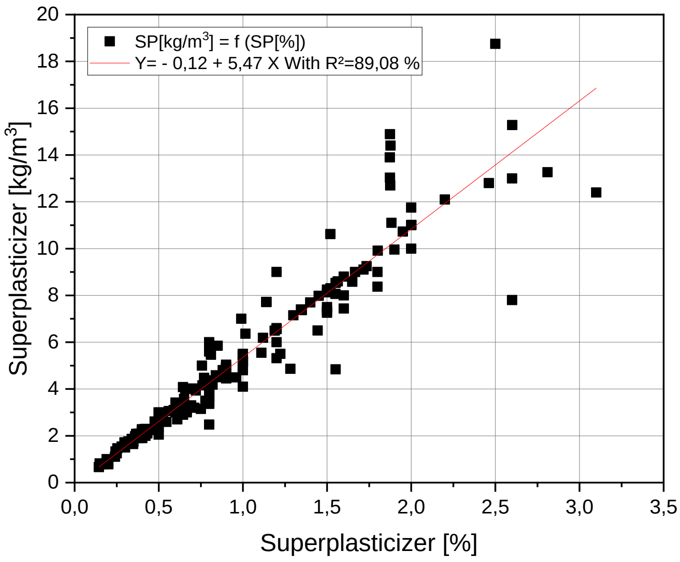

Fig. 9. Superplasticizer dosage [kg/m^3] as a function of superplasticizer percentage

5. Conclusions

This literature review presents a comprehensive analysis of self-compacting concrete (SCC), focusing on admixtures and examining rheology through tests such as the Abrams cone slump flow, T500 flow time, L-box blocking ratio, and V-funnel flow time. The study revealed that the sole admixture dosage used was not sufficient to accurately reflect the desired SCC rheology, with divergent results despite similar dosages of high-range water-reducing admixtures from different suppliers.

Two main parameters, water and admixture, must be considered to achieve a well-defined rheology. Increasing the water dosage linearly increased the SCC rheology, whereas each admixture exhibited unique behavior. The combination of both allows for the determination of an "equivalent water content." This suggests that each admixture has a specific coefficient K that depends on the molecular type and solid content of the admixture. This coefficient K, an empirical factor, is crucial for adjusting the required water dosage to obtain comparable rheological results between different SCC mixtures.

It is possible to obtain the same rheological results with SCC compositions, with or without supplementary cementitious materials (SCMs) such as fly ash, used in this study, by using the same water and admixture dosages. Furthermore, these results can be achieved by varying the water and admixture proportions, either using a low admixture dosage with a high water dosage or using a high vice versa. The first option, which is less expensive, promotes the creation of concrete with high porosity, whereas the second option allows for achieving considerable strength, high granular compactness, and increased durability.

The analysis also highlights the importance of the equivalence coefficient, K, in achieving similar rheology between different types of SCC by adjusting the water dosage relative to the admixture dosage. This study paves the way for new research to standardize coefficient K, which offers a standardized and efficient method for admixture producers and construction professionals to optimize admixture use in concrete formulation, facilitating the precise formulation of concrete tailored to specific requirements.

By integrating this understanding into formulation and standardization practices, it is possible to improve the predictability and consistency of fresh and hardened concrete properties while stimulating innovation in the development of more efficient admixtures. Establishing an admixture classification based on a protocol that includes the coefficient K would standardize the industry and improve the quality of the final products. This classification would also foster continuous innovation in admixture development, meeting the evolving needs of modern construction projects in terms of performance, efficiency, and long-term durability.

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