Table 2 Average pressure before and after external injection

Type of pipeline	Type of concrete	Injection rate, ρ_c (%)	Average pressure (bar)	
			No injection	External injection
L1	Mix.1	0.088	29.6	18.6
		0.120	28.3	14.6
		0.136	16.0	7.9
	Mix.2	0.077	31.6	15.0
		0.112	33.0	15.1
		0.126	22.6	9.0
	Mix.3	0.129	42.4	30.2
		0.147	39.0	26.3
		0.192	31.8	17.6
L2	Mix.1	0.125	21.4	9.9
		0.188	24.0	10.3
		0.250	23.4	9.4
	Mix.3	0.123	75.2	55.2
		0.200	71.3	40.7
		0.284	100.3	52.3
L3	Mix.1	0.190	62.8	26.3

Fig. 11 shows the relation between ρ_c and pressure drop(r_p) according to concrete mixture. Pressure drop, r_p can be calculated following Eq. (2),

$$r_p = \frac{P_{NI} - P_{EI}}{P_{NI}} \times 100 \tag{2}$$

Where, P_{NI} is averaged pressure before external injection (bar), P_{EI} is averaged pressure after external injection (bar).

As injection rate increases, pumping pressure decreases further. The pressure decreased from a minimum of 26.6 % to a maximum of 60.2 %. In the same ρ_c, pumpability of Mix.1 and Mix.2 are greatly improved than Mix.3.

4.2 Strength

Fig. 12 shows variation of compressive strengths according to injection rate ρ_c. Mix.1 and Mix.2 have no change in compressive strength even when ρ_c increases. Compressive strength of Mix.3 was slightly reduced when ρ_c was greater than 0.2 %. However, considering inevitable experimental error or uncertainty of concrete property, the compressive strength due to external injection seems to be unchanged.

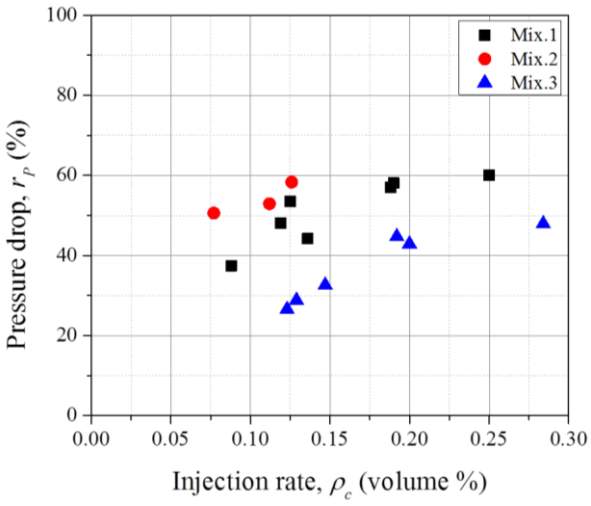

Fig. 11 Relationship between injection rate(ρ_c) and pressure drop(r_p)

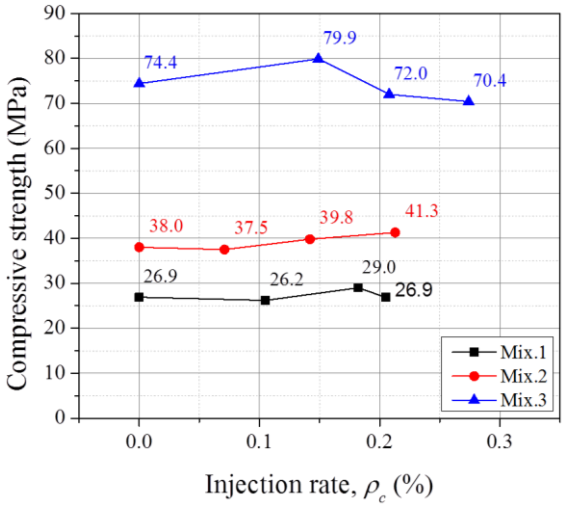

Fig. 12 Variation of compressive strength according to injection rate

5. CONCLUSIONS

Based on the results of this experimental investigation, the following conclusions are drawn:

1. In this study, a new method to externally inject viscosity reducing agent for lubricating layer was proposed.
2. Real-scale pumping tests using three concrete mixtures were performed and real-time pressure was measured during the pumping. It was confirmed that the pumping pressure significantly decreased from 26.6 % to 60.2 % after injecting the agent.
3. Compressive strength of concrete mixtures were measured at 28 days of age. The change in compressive strength due to external injection was insignificant.

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