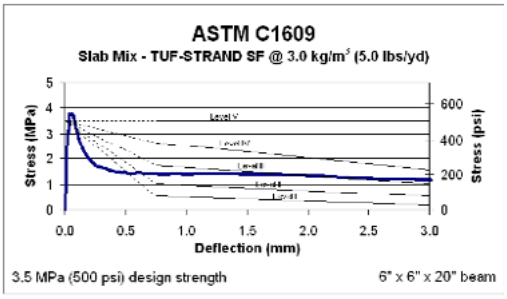
# PERFORMANCE-BASED SPECIFICATIONS FOR FIBER-REINFORCED CONCRETE (FRC)

## What is the difference between ARS (from C1399) and $R_{e3}$ (from C1609)?

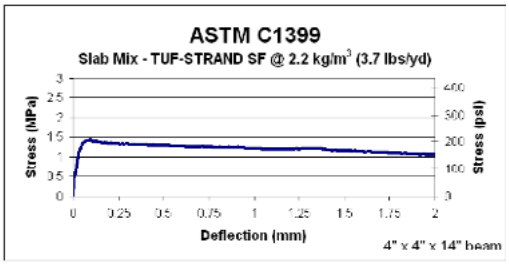
The addition of macro fibers to concrete can significantly improve the ductility and flexural capacity (toughness) of concrete. Flexural testing to obtain the post-peak response is essential for characterizing the performance of FRC. Currently, there are two standard test methods used in North America, ASTM C1399 and ASTM C1609, to measure the toughness of FRC beam samples. These "closed-loop" tests are conducted to obtain the load-deflection curves and the "residual strength". This parameter shows how much load (or stress) can be applied to a cracked section. Different fiber types and dosages provide different residual strength values.

When flexural tests are performed according to ASTM C1609, the parameter $R_{e3}$ (or RT,150 in the current C1609 version) is used to characterize the flexural toughness of fiber-reinforced concrete. This parameter is called "equivalent flexural strength ratio" and is expressed as a percentage. This indirectly shows the ratio of the flexural loads that can be carried by the fibers once the section is cracked and compared to the peak load (or modulus of rupture). The value of $R_{e3}$ can be calculated from either the existing steel reinforcement or the details of the loads and sub-base properties. It should also be noted that the value of $R_{e3}$ can vary between concrete mixes and the determination of the appropriate fiber dosage should always be tested with known materials and conditions. Once established, an example specification may read: FRC design shall provide a minimum $R_{e3}$ value of 35%; For this example, a TUF-STRAND SF dosage rate of 5 lb/yd$^3$ (3 kg/m$^3$) would be used based on internal test results.




| $P_{150,0.75}$ | $f_{150,0.75}$ | $P_{150,3.0}$ | $f_{150,3.0}$ | $T_{150,3.0}$ | JSCE | $R_{e3}$ (%) |
|---|---|---|---|---|---|---|
| 10.5 kN | 1.4 MPa | 9.0 kN | 1.2 MPa | 35 J | 1.41 MPa | 34.8 |
| 2360 lbs | 200 psi | 2020 lbs | 175 psi | 310 in lb | 205 psi | |

single test analysis - individual results may vary




| Average Residual Strength (ARS) at given deflection | | | | | |
|---|---|---|---|---|---|
| deflection | 0.5 mm | 0.75 mm | 1 mm | 1.25 mm | Average |
| ARS - MPa | 1.29 | 1.24 | 1.21 | 1.19 | 1.23 |
| ARS - psi | 187 | 180 | 176 | 172 | 179 |

single test analysis - individual results may vary

While both ASTM C1609 and C1399 measure the load to deflection response in a post-crack state, these two tests can yield different results due to the configuration of the testing method. C1609, due to its more complicated equipment requirements, can be more expensive and difficult to conduct but the results are typically more accurate and conservative towards establishing a required fiber dosage by design. C1399 is an easier and less expensive test and more laboratories can conduct it, therefore, ARS is also acceptable and is currently used in many specifications. It is the responsibility of the design professional to determine which test method to specify and determine the appropriate dosage rate of a specific fiber type. The Euclid Chemical Company recommends the development of performance based specifications requiring manufacturers to carry testing data to support design requirements. This is due to the fact that not all fibers will provide the same performance at similar dosage rates. Euclid Chemical has also developed computer spreadsheets and mobile applications to assist design professionals in determining the correct dosage rate of TUF-STRAND SF once Re3 or ARS values have been determined.

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