Test results on compressive strength anisotropy in steel fibre reinforced shotcrete

by G.J. Keyter* and K. Drescher†

Synopsis

Recently, work was carried out by the Shotcrete Working Group to study anisotropy in steel fibre reinforced shotcrete using strain-controlled, compressive strength testing methods. The shotcrete materials used and specimen preparation procedures as well as testing methods are described. The test results are discussed and it is concluded that, because of the anisotropic nature of fibre reinforced shotcrete, it may be worthwhile investigating the degree of such anisotropy in practice using strain-controlled, strength testing techniques.

Introduction

Shotcrete is an established component of tunnel support and comprises a quick and convenient method of construction. It is cost-effective, structurally outstanding, versatile and ensures immediate safety in the working place. Shotcrete provides a unique means of support in mining tunnels in which conditions vary widely. It serves for example as a relatively thin application to secure fragments of rock in the walls of excavations that are otherwise stable. In other instances, shotcrete contributes to the support of ground subject to tunnel convergence of considerable extent. In key access ways, it is on occasion subject to impact loads of varying magnitude and frequency. Together with mesh or fibre reinforcement and bolts and lacing, shotcrete comprises a support system of which the key attributes are ductility and fatigue strength.

Considerable effort has been spent in recent years by the Shotcrete Working Group to determine whether steel or other types of fibre can be used instead of mesh to reinforce shotcrete. As part of this programme, a limited number of strain-controlled, uniaxial compression tests were carried out on cores of steel fibre reinforced shotcrete (SFRS).

The materials used as well as the spraying, curing and testing procedures are described in this paper. The results of the tests are presented and the findings discussed. Finally, some conclusions are drawn based on the observations and findings from the study.

Shotcrete materials

Aggregate

The aggregate used for this study was a river sand and was obtained from a source near Carletonville. A typical grading of the aggregate is shown in Figure 1. The material was supplied in 30 kg bags at a moisture content of approximately 5%.

It should be noted that the aggregate grading did not fully comply with the recommended grading envelope for dry mix shotcrete as per SABS 1083:1994.

Steel fibre

Dramix steel fibre (RC 80/40 BN) was used in the study. The fibres are cold drawn, bright steel, low carbon wire with a tensile strength of 1100 MPa. The fibres are round in cross-section and are collated. The fibres have a length of 40 mm and a 0.5 mm diameter with an aspect ratio of 80.

Mix design

The mix design used for the dry mix shotcrete consisted of (per 30 kg bag of material):

Material	*Mass (kg)*
Sand (decomposed granite)	23.4
Ordinary Portland cement	4.9
Pozzfill (flyash)	1.3
Silica fume	0.4
One 30 kg bag of material	**30.0**

Two additives were added to the mix during mixing and spraying. Approximately 0.1% GDS[3] by mass of aggregate was added to the mix in the mixer in powder form. In

* *SRK Consulting.*
† *CSIR Division of Mining Technology.*
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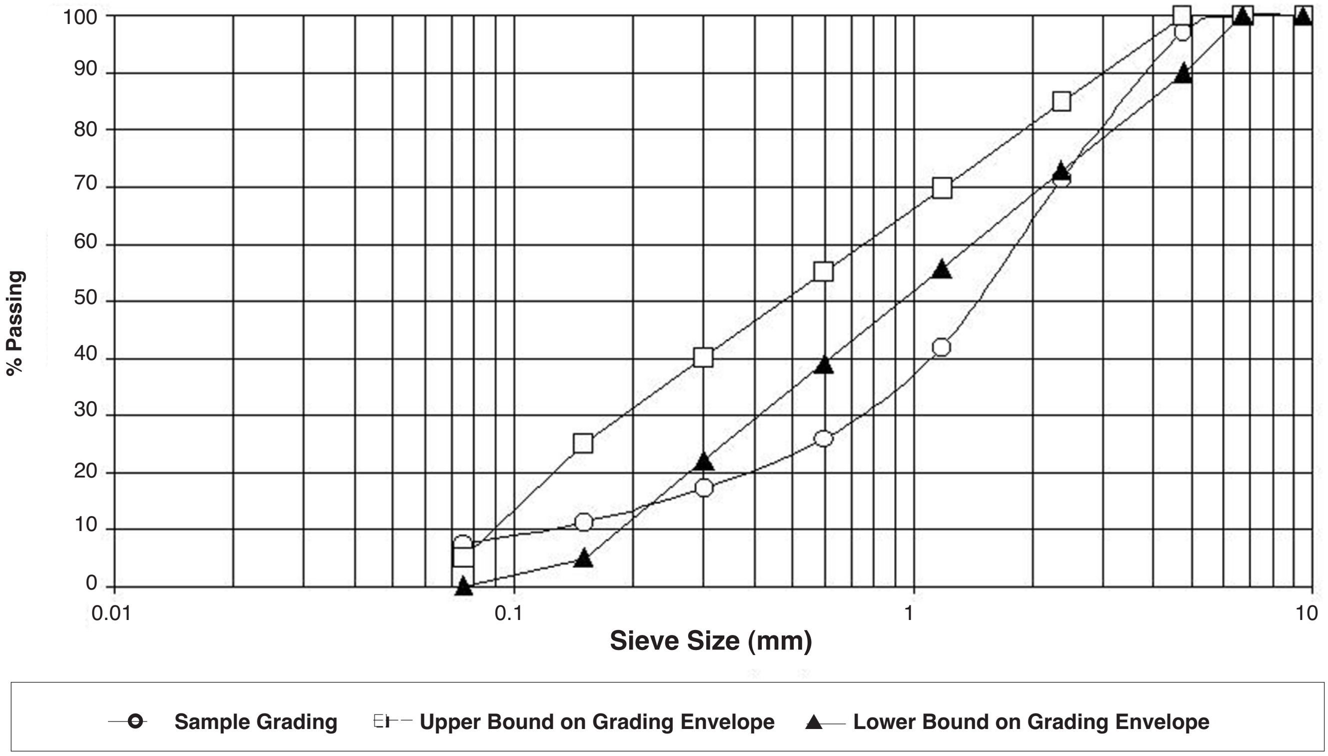

Figure 1—Typical grading of aggregate used in dry mix shotcrete

addition, between 2% and 3% of GDS liquid by volume of water flowing through the dosing pump, was added to the mix during spraying via the water supply line.

Preparation

Mixing and spraying procedures

The slightly moist shotcrete material was mixed using a reconditioned Winget 600/400R drum mixer. The Dramix steel fibres in their collated form were immersed in water for about 15 minutes before adding the fibre to the mix to ensure that the glue on the fibre dissolved completely. The fibre was added to the mix in small quantities to prevent balling of the fibre and to ensure a uniform distribution of fibre throughout the mix. The quantity of fibre added equalled 2% of the mass of the moist sand/cement mix in the mixer. Water was then added to increase the moisture content to about 12% to improve the flow characteristics and workability of the mix so that it could be sprayed using a shotcreting machine.

The SFRS was sprayed into steel formers, trapezoidal in form with a depth of 180 mm, a top area of 500 mm by 700 mm and a bottom area of 300 mm by 500 mm.

Curing procedures

The formers were placed inside a curing tent. The SFRS panels inside the formers were kept wet by means of a system of micro-sprinklers in the roof of the curing tent. The temperature inside the curing tent was maintained at an average of $26\frac{1}{2}$°C ± $1\frac{1}{2}$°C by means of an air conditioner.

Curing continued for a period of 21 days. At 21 days, the curing tent was opened and the formers with the SFRS panels taken to Lafarge South Africa's Technical Services laboratory for drilling of cores.

Specimen preparation

Cylindrical cores were drilled from the SFRS panels. Two cores were drilled at right-angles to the direction of spraying of the SFRS and two other cores were drilled in the direction of spraying of the SFRS. The specimen ends were cut and polished at the CSIR Miningtek laboratory to be planar and parallel in order to reduce friction as well as end effects during testing.

Description of testing method

The tests were conducted using an MTS 815 servo-controlled Rock Testing System at the University of the Witwatersrand. Deformation measurements were made using the main LVDT (Linear Voltage Differential Transformer), which also measures the displacement of the loading piston. A set of two smaller LVDT's was also used to measure deformation of the specimen as well as rotation of the top cap during testing and these were attached on either side of the top loading cap.

The specimens were tested in axial deformation control mode at a constant strain rate. The MTS machine is controlled by a digital closed-loop system (refer Figure 2). The main LVDT was used as feedback signal. The strain rate used during testing was 750 microstrain per minute.

Test results and discussion

The results of the strain-controlled, direct compression tests obtained from cylindrical cores of Dramix SFRS are presented in Figures 3a to 3d.

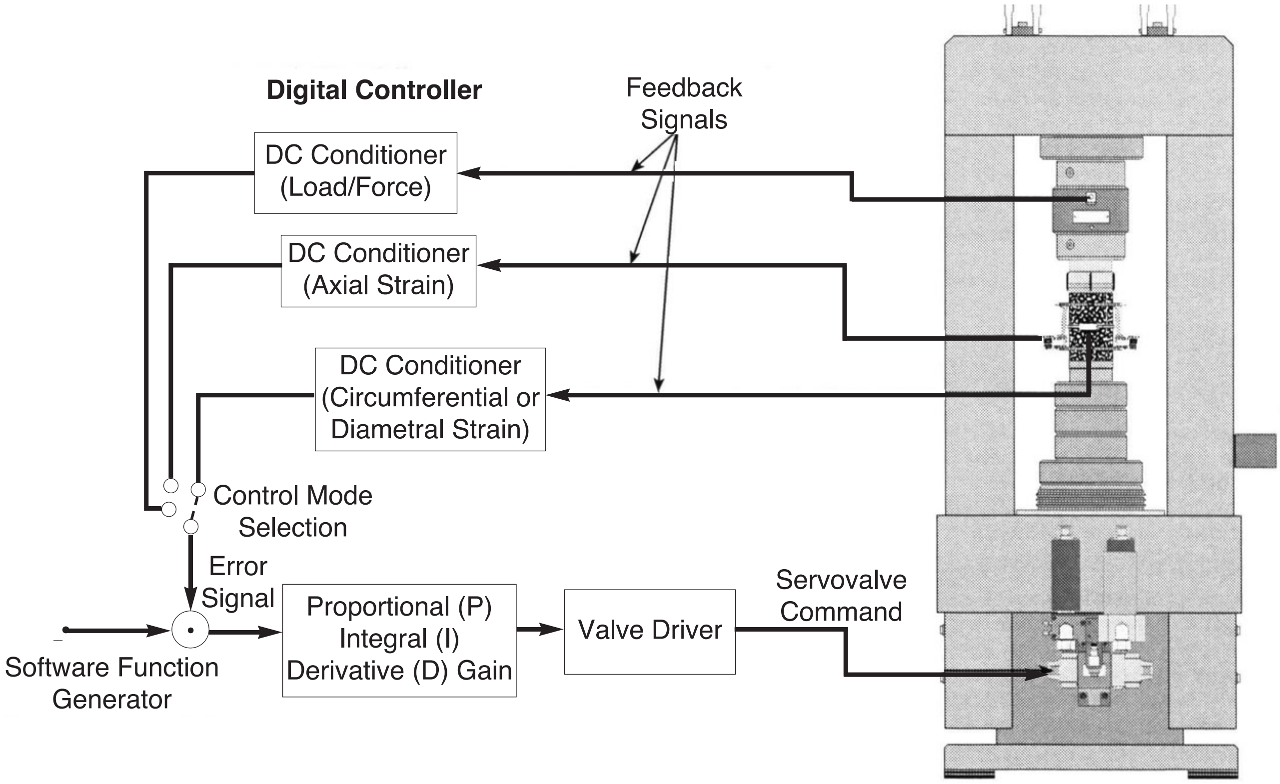

Figure 2—Schematic diagram of MTS 815 servo-controlled rock testing system

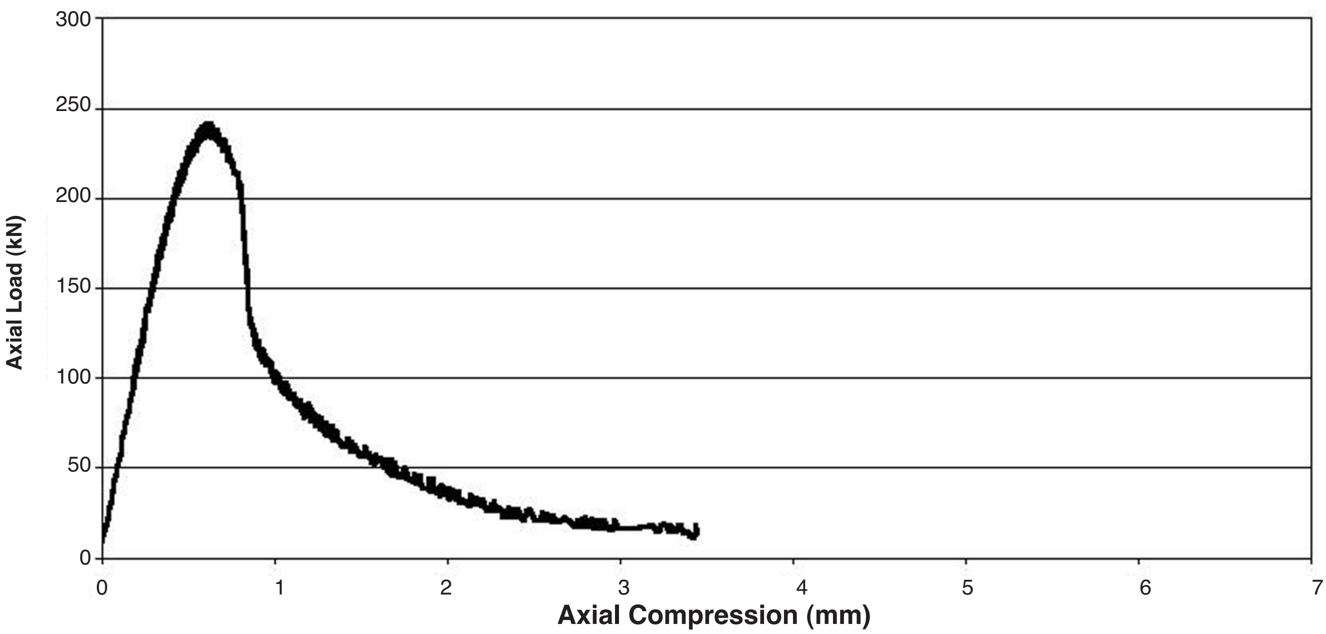

Figure 3a—Strain-controlled, compression test at right angels to direction of spraying

Based on the results presented in Figures 3a to 3d, the following observations may be made.

- ➤ The good correlation in the test results from cores drilled in the same direction suggests that specimen preparation was well controlled and that material variation (i.e. non-homogeneity) was reduced to a minimum.
- ➤ The Dramix SFRS material is distinctly anisotropic.

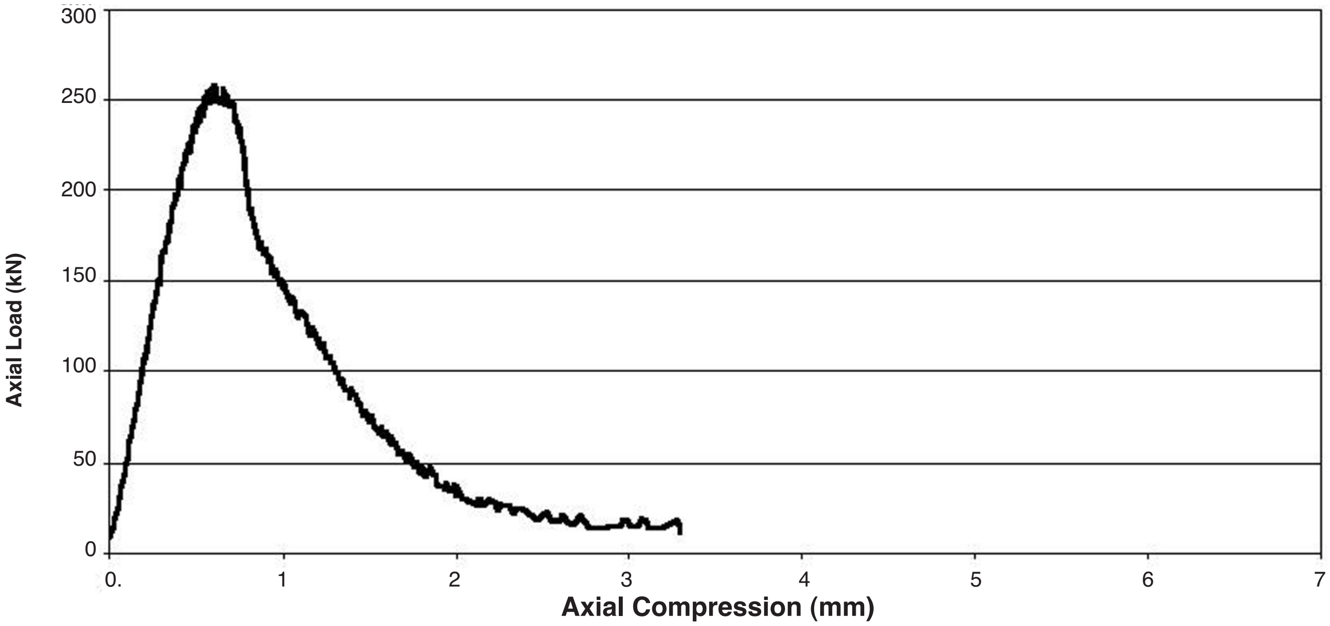

Figure 3b—Strain-controlled, compression test at right-angles to direction of spraying

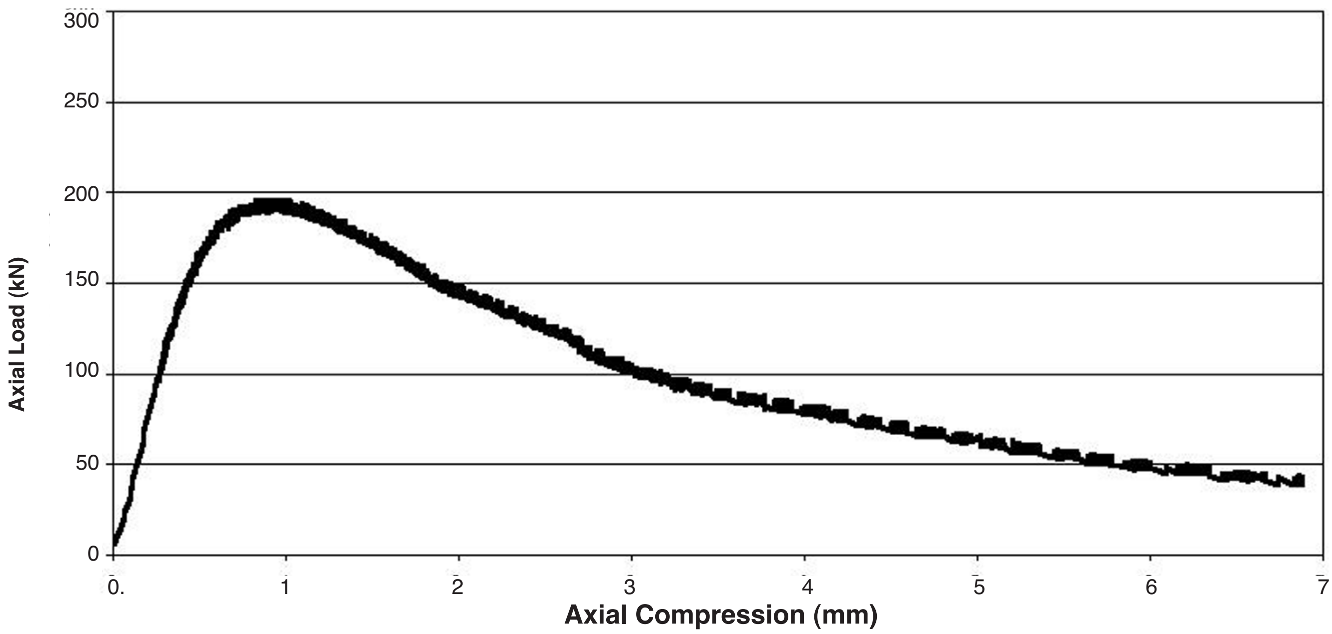

Figure 3c—Strain-controlled, compression test in direction of spraying

- The uniaxial compressive strength of cylindrical cores of SFRS drilled at right-angles to the direction of spraying (Figures 3a and 3b) was approximately 25 % higher than that of SFRS cores drilled in the direction of spraying (Figures 3c and 3d). This may be attributed to fibre orientation with more fibres being orientated at right-angles to the direction of spraying.
- The cores drilled at right-angles to the direction of spraying (Figures 3a and 3b) showed a marked brittleness whereas the cores drilled in the direction of spraying showed a more plastic post-peak behaviour (Figures 3c and 3d). Again, this may be attributed to fibre orientation with more fibres bridging cracks that formed during testing of cores drilled in the direction of spraying than in the case of cores drilled at right-angles to the direction of spraying.
- Finally, it is worthwhile to note that a considerable amount of energy is absorbed during post-peak deformation of SFRS and that this phenomenon may be successfully studied in a repeatable manner using strain-controlled strength testing methods.

Conclusions

In practice, cores of fibre-reinforced shotcrete (FRS) are normally drilled in the direction of spraying before subjecting

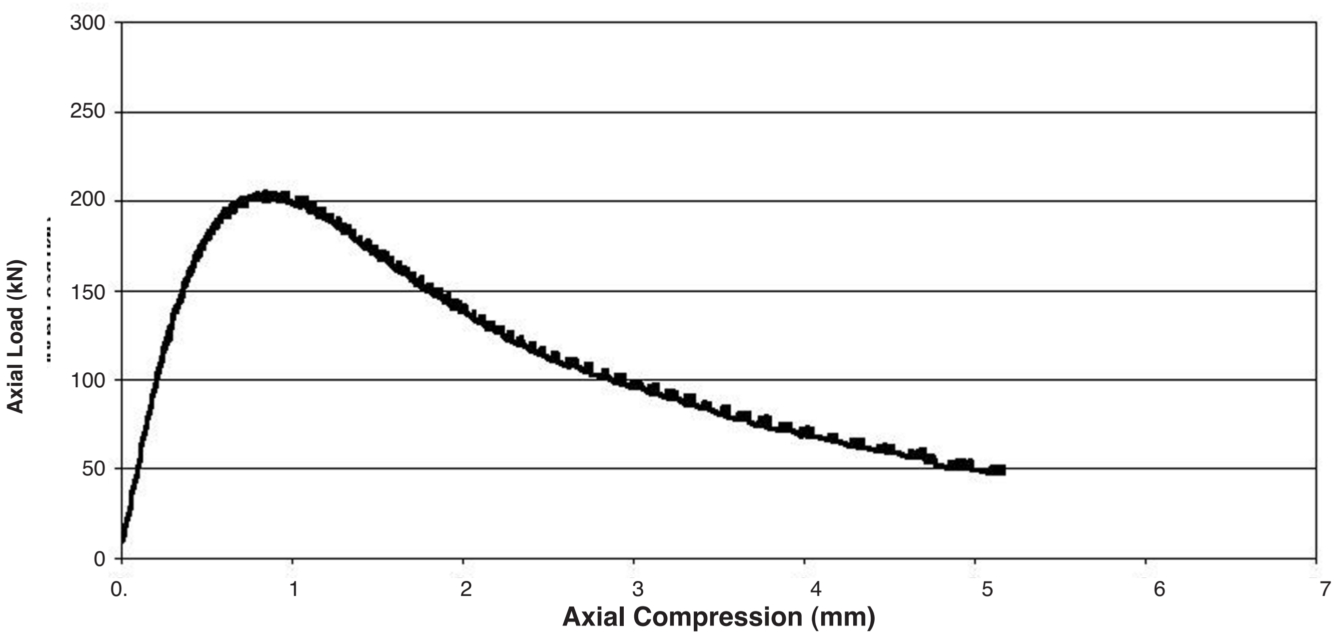

Figure 3d—Strain-controlled, compression test in direction of spraying

the cores to strength testing. The reason for this practice is probably that it is easier to drill cores in the direction of spraying from FRS panels than at right-angles to the direction of spraying. However, when FRS is used as a lining on slopes or in tunnels, the lining will normally be subjected to bending moments out of the plane of the lining. The resulting compressive and tensile stresses will therefore be acting within the lining (i.e. at right-angles to the direction of spraying) rather than at right-angles to the lining (i.e. in the direction of spraying). It may, therefore, in practice be prudent to study the peak strength and load-deformation behaviour of FRS in the direction of loading as well, i.e. at right-angles to the direction of spraying. Also, testing cores drilled in one direction only may give rise to inaccurate design and prediction.

Finally, strain-controlled strength testing of FRS may be a viable alternative to spraying and testing of beams and panels when studying the energy absorbing capacity of different types of FRS on a comparative basis.

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