STRENGTH & RELIABILITY OF SMALLER DIAMETER FIBERS FOR SUBMARINE APPLICATIONS

John Hedgpeth, Scott Bickham, Ian Davis, Sergey Akopov, Nina Burrell, Nikita Korotkov, Amy Millett, Denise Packard, Simit Patel, Jennifer Prater, Garth Scannell, Gabe Sudduth (Corning Incorporated)
Email: hedgpethjm@corning.com

Corning Incorporated, 310 N College Rd, Wilmington, NC 28405

Abstract: This paper showcases smaller diameter fibres, specifically those with a coated diameter of 200 µm, as a viable option for current and future submarine systems. These smaller fibres will enable higher cable capacity, lower overall cost per bit, and sustainability through cable design optimization. To address submarine industry concerns with reliability, we analyse the fibre strength distribution, coating puncture resistance, and optical performance, as compared to standard diameter fibres. Building on over a decade of terrestrial cabling experience with processing smaller coated diameter fibres, we share best practices for fibre handling to avoid potential damage mechanisms.

1. MARKET DRIVERS

Intercontinental bandwidth demand will grow close to 40% annually, over the next 5 years [1]. Likewise, the industry is aiming to provide cables capable of 1 Pb/s, which can improve the economics of system production and deployment. A logical next step to address additional growth and capacity needs will be the adoption of 200 µm submarine fibres to bridge the next 5 years while work continues with other novel fibres, such as multi-core and fibres with even smaller diameters.

Meeting this high bandwidth need requires the subsea industry to produce more cables and/or more optical paths per cable. Industry assets – cabling plants and marine resources – are already operating at a high utilization rate. System houses and network installers are continuously investing in cabling and installation capacity to stay ahead of their customers.

At the same time, to optimize asset investments and reduce overall cost per bit, the industry and end-users are considering smaller diameter fibres, such as the 200 µm coated diameter fibres we discuss here, to increase cable capacity and economize on installation through reduced material costs. Being able to utilize smaller diameter fibres in existing cable designs has the added benefit of industry-proven deployment success and maintaining the same cabling form factor to enable efficient ship loading and deployment.

Space Division Multiplexing (SDM) advantages of 200 µm coated diameter fibres are clear, as more fibres can fit into any given cable compared to the standard 250 µm diameter fibres being deployed today. For example, a 20 mm outer diameter (OD) cable can move from 24 x standard OD fibre pairs to 36 x 200 µm fibre pairs, while maintaining approximately the same fill ratio.

Alternatively, an end-user may opt to maintain cable capacity but achieve cost savings with a smaller cable that streamlines marine deployments and thus significantly saves on installation costs. For instance, smaller fibres might enable a 14 mm cable to meet the same system design requirements as the current 20 mm cables being deployed today. Selection of a smaller OD cable also allows for a single cable ship to store significantly longer cable length.

2. 200 µm COATED DIAMETER FIBER BASICS

When developing a smaller form factor optical fibre, one approach is through reduction in the outer coating diameter. Figure 1 shows a comparison of 250 µm to 200 µm coated diameter fibre and the 36% reduction in cross-sectional area.

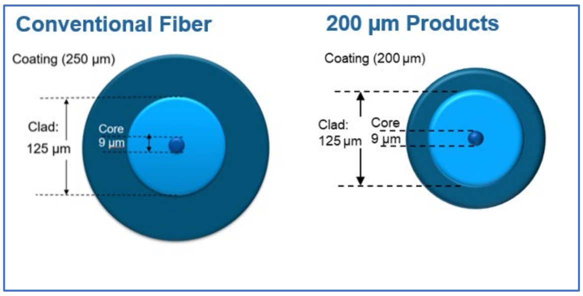

Figure 1: Cross-sectional Comparison of Standard to 200 µm Coated Diameter Fibres

Note that the glass diameter itself does not change in this case. This enables similar overall glass strength and optical performance, as well as maintaining established processes and equipment for fibre splicing, termination, etc.

However, the thickness of the coating layers is reduced, which can impact other performance factors. Conventional fibre coatings are designed with two layers. The outer coating layer or secondary coating protects the fibre from abrasions and punctures during handling processes for cabling. The softer inner coating layer or primary coating acts as a cushion to absorb stresses which could potentially cause elevated microbend responses and impact overall attenuation.

In the case of 200 µm coated diameter fibre, the thickness of both the primary and secondary coating layers are reduced from those of standard 250 µm diameter fibres. The trade-off for higher fibre core density will be lower puncture resistance of the fibre coating and potentially more microbend susceptibility in certain cable designs.

Concerns over this reduction in coating and impacts on performance can be allayed by following best practices during fibre handling and cable manufacturing. We note that 200 µm coated diameter fibre is already an established solution for tight-packed, mini-cables to increase the fibre density in space-constrained terrestrial access networks.

3. GLASS STRENGTH

Strength and reliability are integral to optical fibre and cable manufacturing [2]. In the submarine industry there is a much higher concern based on the cost and logistics of at-sea repairs if performance falls short of expectations.

In the case of 200 µm coated diameter fibres, the diameter of the uncoated glass remains unchanged. However, it's still important to evaluate both intrinsic and extrinsic strength distributions to understand if there should be concerns with overall strength and reliability.

Short gauge length fibre samples were tested in accordance with IEC 60793-1-31, "Measurement methods and test procedures - Tensile strength," to map out the tensile strength of the 200 µm fibres by dynamic loading and characterizing the strength in the intrinsic region.

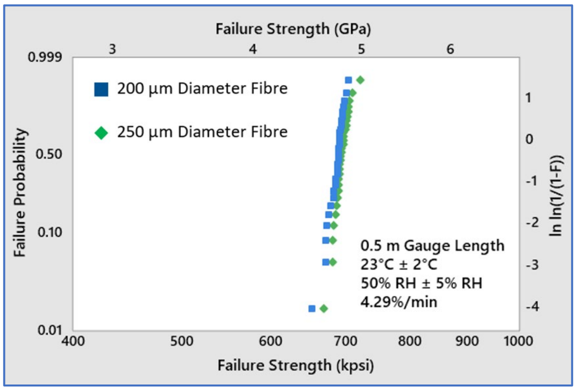

Figure 2: Intrinsic Strength Distribution

As represented in Figure 2, the results indicate comparable intrinsic strength between the 200 µm and 250 µm coated diameter fibres, which is to be expected as the coating diameter is the only difference between these fibres and the mechanical properties of the cladding are identical.

The strength data shown in Figure 2 represents the intrinsic strength flaws that reside on the glass surface. From a reliability standpoint, for optical fibre the strength-controlling flaws that are relevant to failure probability are not the high strength flaws measured by 0.5 m gauge length testing. Rather, they are the low strength flaws that occur less frequently than once per km. The main reliability concern of 200 µm coated diameter fibre is thus an increased risk of damage through the coating, which will show up in the low-strength flaw population rather than in the high-strength flaw population measured in 0.5 m gauge length testing.

To efficiently measure this population of flaws, fibre was tested in 20 m lengths using a continuous rotating capstan fibre tester (CRCFT) up to a stress of 600 kpsi [3]. Over 600 km each of standard diameter coloured fibre and 200 µm coloured fibre of the same glass type were tested after being proof-tested at 200 kpsi, which is standard for submarine application fibres. During testing, break stresses were recorded and survivors (intervals showing no breaks) were identified as suspensions. Resulting Weibull distributions are shown in Figure 3.

To show the similarity between the distributions, 95% confidence intervals are shown in the shaded areas. From this analysis, it can be concluded that the as drawn and screened strength distributions for 200 µm and 250 µm coated diameter fibres are not statistically different, with no indication of any impact on the delivered fibre performance that would be of concern to submarine cablers.

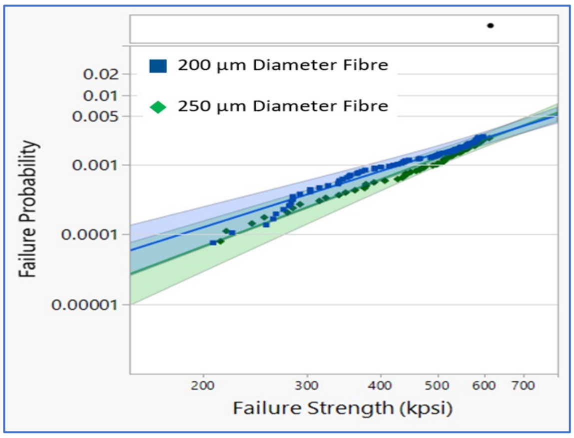

Figure 3: Extrinsic Strength Distribution

4. PUNCTURE RESISTANCE

As mentioned in the prior section on glass strength, one of the key concerns in going to a reduced diameter coating is the reduction in secondary or outer protective coating layer.

There are several test methods which allow for comparative analysis of puncture resistance [4]. Figure 4 shows a comparison using an indentation method, where the device being used to create the damage is well controlled. As can be seen in Figure 4, the threshold load for puncture correlates with the cross-sectional area of the secondary coating. Points plotted in Figure 4 represent minimum and maximum secondary wall thickness for each fibre type. As expected, 200 µm coated diameter fibres do exhibit a lower puncture resistance when compared to standard diameter fibre.

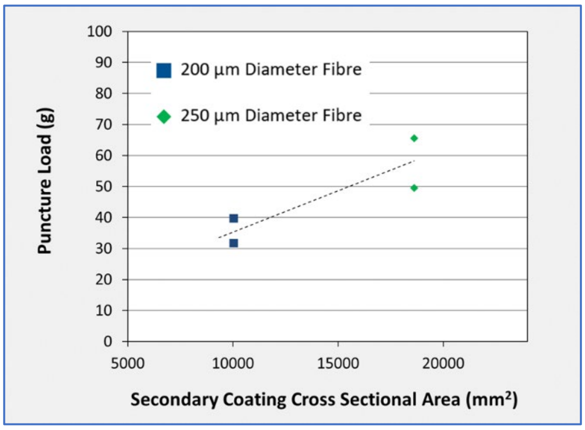

Figure 4: Puncture Resistance Testing

With the consequential reduction in the thickness of the protective coating, a cable manufacturer might be concerned and expect to encounter more breaks per kilometre than is typical with standard OD fibre. However, these concerns can be minimized by fibre manufacturing seeing equivalent break rates for 200 µm coated diameter fibre as compared with standard diameter fibre and maintaining the final 200 kpsi screening required for submarine applications.

As mentioned earlier, terrestrial cabling has used 200 µm coated diameter fibre for over 10 years in challenging cable designs while achieving similar break rates during processing achievable as seen with standard coated diameter fibres. This has been attributed to good housekeeping and attention to fibre contact points [6].

5. OPTICAL PERFORMANCE

In the case of 200 µm coated diameter fibre, it will have similar optical performance to standard diameter fibre since the glass itself remains unchanged.

For attenuation, Figure 5 shows an overlay of spectral attenuation comparing 200 µm coated diameter fibre to standard fibre of the same glass type.

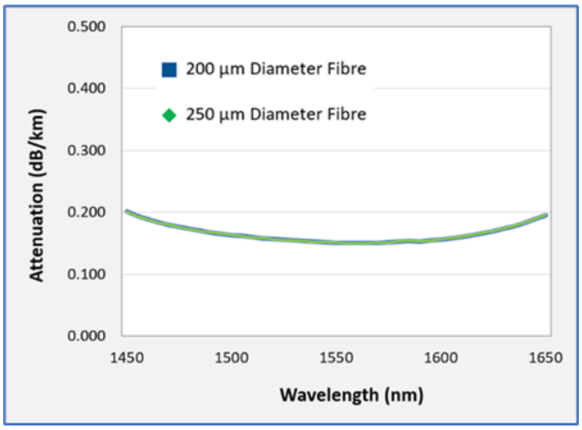

Figure 5: Spectral Attenuation Comparison

Two types of bending are important considerations for cable design, macrobend and microbend. Like attenuation, macrobend is equivalent when comparing 200 µm coated diameter fibre to standard fibre of the same glass type, since macrobend is determined by the glass profile.

Microbend can be influenced by changes to the coating geometry and should be considered as part of cable design for smaller diameter fibres. However, it is encouraging that terrestrial cable designs incorporating 200 µm coated diameter fibre with even higher fill ratios than submarine cables have met attenuation compliance specifications, even at extreme low temperatures which increases the potential to see a microbend response.

Since there is no current industry standard test method for microbend, developmental cables with control standard fibres are considered the best method to understand specific cable design influences [5].

6. SPLICING

When splicing reduced coated diameter fibres, performance can be achieved with parity to standard diameter fibres, as seen in Table 1, showing a comparison of submarine fibre splicing in a cleanroom operation for span preparation.

Table 1: Splicing Performance

Coating OD	250 µm	200 µm
Avg	0.02	0.02
Std Dev	0.01	0.01
Min	0.00	0.00
Max	0.07	0.06

For splicing reduced coating fibres to standard fibres, core alignment splicers are unaffected by the fibre coating diameter. Special care should be taken with V-groove splicers to ensure that the coating has been fully removed from fibre, leaving only the glass portion to sit in the V-groove.

To address another component of splicing, reduced diameter fibres have been tested to compare coating strip force against existing standard diameter fibres. Figure 6 shows the peak and average measured coating strip force for reduced coated diameter fibre compared to standard diameter fibre.

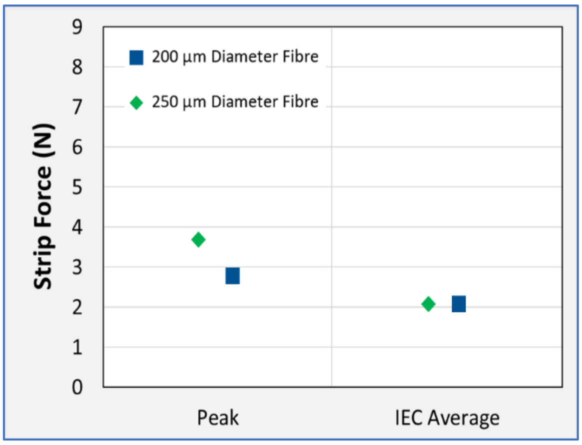

Figure 6. Strip Force Comparison

Based on this analysis and terrestrial cabling experience, fibre handling and processing will be very similar. Stripping tools are commercially available and suitable for processing both 200 µm and 250 µm fibre types.

7. CABLING BEST PRACTICES

The reduced puncture resistance of 200 µm coated diameter fibre may make the fibre more vulnerable to damage to the coating surface that will ultimately compromise the glass, which can lead to breaks. Several mechanisms in the cabling process can damage fibre coating: abrasions from moving across rough or uncleaned pulleys, fibre moving across static parts (like seized pulleys), general debris within the cable manufacturing process and fibre whip events which may occur during winding processes.

However, even with lower puncture resistance, incoming 200 µm coated diameter fibre strength and reliability to the cable manufacturer has been demonstrated to be comparable to standard coated diameter fibre. This can be seen through similarity in breaks during proof testing and the fibre meeting the final 200 kpsi proof test required for submarine applications. Protocols on cleanliness of the work environment and process equipment, notably pulleys, are considered essential parts of the fibre manufacturing process.

On the cable manufacturing side, similar actions should be reviewed to ensure optimal processing performance with reduced coating fibres. The following are four key areas to consider:

- To qualify cabling manufacturing process, request mechanical-grade samples to run along with control standard diameter samples, comparing processing metrics, e.g., break rates.
- Pulleys should be checked regularly and changed if issues are found with nicks, roughness, or reduced motion. Additionally, the pulley surface finish may need to be monitored to minimize abrasion potential.
- Check payout equipment for proper tension and alignment, which can reduce the risk of fibre contacting other parts of the equipment.
- To minimize impact of environmental contaminants and processing debris, we recommend increasing this frequency of deep cleans, especially for fibre-contact surfaces.

With careful consideration to the best practices mentioned above, 200 µm coated diameter fibres can be successfully processed without adversely impacting the cabling process or cabled long-term reliability.

8. CONCLUSION

With growing needs in the submarine cable industry to increase carrying capacity per cable and reduce cost of manufacturing / installation, reduced coating diameter optical fibres can meet these challenges with proven track record from >10 years of use in challenging terrestrial cabling designs.

A key concern is strength and reliability in the higher liability submarine application space. With the glass strength remaining unchanged, while the reduction in coating provides slightly less protection, application of best practices in the cabling process can be used to help mitigate risk of perforations or other damage to the protective coating.

With correct procedures in place, reduced coating diameter fibre can be operated with the same confidence as derived from conventional coating diameter products.

9. REFERENCES

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