The role of building and curing in fender performance

Last month we highlighted the importance of high quality fenders being an essential part of port infrastructure, providing protection for terminals and berthing vessels alike. In this article, Richard Hepworth, President, Trelleborg Marine Systems discusses recent work published about rubber compound ingredients, compound mixing and material modulus and looks at the importance of the building and curing process in the manufacture of high quality fenders.

Trelleborg has previously worked to raise awareness of the performance issues surrounding lower cost, lower quality fenders, and those manufactured using low quality rubber compound ingredients. To highlight this issue, two analytical tests were developed, intended to help buyers determine the quality of procured fenders. These tests require just a small sample from the fender body, which has no impact on overall fender performance. But before then, there are a series of best practice parameters to consider in the manufacture of a high quality, engineered rubber fender.

The mixing process

A rubber compound, produced using a superior rubber formulation, doesn't guarantee a high quality fender: one that is capable of absorbing the correct amount of energy. If the mixing process uses inferior equipment or the process is poorly controlled, the rubber compound will not perform correctly. A high quality compound is one where the carbon black is broken down and distributed uniformly throughout the rubber matrix. Carbon black is supplied to manufacturers in the form of granules. These granules can be broken down into smaller and smaller fragments: granule to agglomerate to aggregate to nanoparticle. Ideally, carbon black should be broken down into nanoparticles and distributed into the rubber matrix. However, it requires an extremely advanced mixing machine to break it down to even aggregate level, the bare minimum to ensure an intimate dispersion within the rubber matrix. The percentage of carbon black dispersion in the final compound is what controls the quality of the end product. Poor dispersion can lead to damaging effects such as reduced product life, as well as poor performance, appearance, processing characteristics, or even product uniformity. To break carbon black down to aggregate level and ensure a uniform distribution throughout the rubber matrix, rubber and carbon black must undergo a number of major steps inside a mixer:

- Incorporation of carbon black: when carbon black is mixed with the rubber, the carbon black agglomerates get encapsulated by the rubber in a process called wetting or incorporation.
- Distribution of carbon black: the rubber then penetrates into the void space of the carbon black agglomerates. As the rubber penetrates through the narrow channels between the agglomerates, bound rubber is formed. The bound rubber helps in breaking agglomerates to aggregates.
- Dispersion of carbon black: dispersion is a slow erosion phase in which agglomerates are downsized to aggregate level, as a result of stress generated through the mixing process.

To achieve a high and uniform carbon black dispersion, operators must ensure close control over the mixing process and the machinery used in this process must be in very good condition.

Measuring for success

The modulus of rubber compounds, and the fatigue life of fenders, are dependent on carbon black dispersion, when all other factors are kept constant. This is why Trelleborg suggests the industry move away from using 'hardness' to measure energy absorption, and instead evaluate the uniformity of carbon black dispersion in samples of rubber compounds and final fenders. The modulus (or stiffness) of a rubber compound is the gradient of the stress/strain graph, measured when conducting a tensile strength test on a cured rubber sample. A rubber compound with a higher modulus indicates a higher energy absorption capacity of a fender. Therefore, as a more robust alternative and scientifically correct method, Trelleborg suggests that the industry starts to measure material modulus to describe the performance of rubber. The ASTM standard has a well-established method to test carbon black dispersion in fenders and rubber compounds, which requires only a small sample. A machine called a 'Dispergrader' can be used to evaluate carbon black dispersion in the samples, measuring both the size of the carbon black particles and the uniformity of dispersion. The Dispergrader then provides a percentage rating, allowing engineers to understand the homogeneity of the final mix. It's important that designers, operators and owners of port infrastructure begin to recognise the importance of rubber compound composition, carbon black dispersion and modulus of rubber fenders. All these factors need to be taken into account during the design and procurement process. Long overdue is the appropriate application of rubber technology principles and standards in fender systems, using the same intensity as those applied in steel fabrication. Trelleborg's latest materials research goes even further, highlighting the importance of the building and curing process in manufacturing, another critical step towards best practice rubber fender production.

Molecular orientation

Rubber is a long chain polymer and its strength and performance depends on the alignment or orientation of the long chain molecules in the final product. Molecular orientation in the rubber element of a fender system is critical to its characteristics. Any given rubber slab will have different tensile strength, modulus and other physical properties depending on the direction in which the molecules are oriented. These differences in strength and subsequently, performance, can be substantial.

Optimising manufacturing

The orientation of rubber chains is, in turn, determined by the manufacturing process. Most fenders are produced either by extrusion in to mould, or by filling up moulds with rubber blanks, or wrapping of rubber sheet on a mandrel - this is known as the building process for a fender. The orientation of the molecules inside the mould will differ between each of the above three building processes, significantly impacting the properties of the rubber compound and subsequently the performance of the final fenders. It's essential that due consideration is given to the building process used when assessing fender performance. Despite the importance of the building process on the rubber's molecular orientation and performance of the final product, there have been limited studies in this area. In an effort to raise industry standards, Trelleborg is currently investing significant resource into understanding the impact of these different building processes on fender performance.

The impact of curing

When the building process is complete, curing is the next step in fender manufacturing, and equally important to the quality of the final product. Critically, this is the step that takes soft, commercially unusable rubber fenders and converts them into cured and practical products for use on a quay wall. Curing is a process in which individual long molecules of rubber are converted into a three dimensional network of interconnected chains through chemical cross links. The most important ingredients added to the rubber compound during the curing process are sulphur and accelerators. Accelerators increase the rate of reaction between the rubber molecules and the sulphur, while sulphur is the element that makes the links between rubber chains, ultimately providing strength and durability to the cured rubber material. The final properties of a rubber compound depend on the cross link density and number of sulphur molecules in a link, otherwise described as the type of cross link. Generally, a low sulphur to accelerator ratio leads to cross links with one or two sulphur molecules present. Products from such a curing system exhibit better heat stability, suitable for hot climates. On the other hand, products produced using a higher sulphur to accelerator ratio will have higher tensile strength, tear strength, and fatigue resistance due to having more sulphur molecules in a link. This system provides higher longevity of a product at medium to lower environmental temperature.

Raising standards throughout the process

Trelleborg has recently undertaken a large-scale study to improve understanding of the impact of curing on the performance of rubber fenders, which will be published in due course. The primary purpose of this research has been to develop guidelines that will enable the use of optimum fenders in different application areas, and to improve knowledge-sharing and best-practice across the industry. Trelleborgs' on-going research into materials best practice is part of the company's 'smarter approach initiative', which is designed to elicit excellence across all product ranges and technology development. Whilst Trelleborg is refocussing its business model towards smart, data-driven technologies, the company is also keeping a keen eye on the evolution of its current fender offering to add the most value to specifiers. The next step in this journey will be deep research into testing for specification. The company is working on a process to ensure that performance testing can never be falsified, with a testing procedure taking specifiers and buyers through multiple considerations to ensure that the finished fenders they procure adhere precisely to specification. It's essential that the industry works towards a deeper understanding of the impact of the manufacturing process while ensuring that the mixing quality does not impact product performance. Port owners, operators, contractors and consultants need comprehensive specifications/testing methods covering ingredient selection, mixing procedure and production process to stipulate the performance of finished products. It is Trelleborg's mission to ensure these are made available, to drive up standards across the whole industry. WPD