WHITE PAPER #3

MANUFACTURING AND CURING.

ADVANCED PERFECTION

SHIBATAFENDERTEAM

on the safe side

Contents.

Executive summary.

The ShibataFenderTeam Group pursues the four-part White Paper Series on fender manufacturing with an in-depth illustration of the various manufacturing and curing processes. Paper #3 of the series presents two of the most quality-critical steps in the fender manufacturing process.

While White Paper #1 and #2 established the complex interdependencies between compounding and mixing, the third publication reveals the wide variety of manufacturing and curing methods and how the respective process needs to be adjusted to the fender type, its required performance, and the chosen compound. Since the chosen manufacturing and curing methods directly reflect on the properties of the fender, a responsible and experienced manufacturer always prioritizes the quality of the product and settles for the optimal method.

In Paper #3 of the series, SFT examines manufacturing and curing methods with a focus on the quality-determining parameters pressure, temperature, and time. On this basis, the various possible procedures are introduced. It should be pointed out that more than one method can be used to produce the exact same type of fender but not every method results in the same quality. This fact makes choosing the ideal method subject to long-standing expertise. Looking at the careful consideration of important parameters for both manufacturing and curing, the available methods that reflect in the quality aspects of the fender, establish this part of the SFT White Paper Series as the third cornerstone in high-quality fender production.

SFT White Paper Series.

Sharing profound knowledge with the industry is a part of what makes the SFT White Paper Series a contribution to state-of-the art fender manufacturing standards. Based on Papers #1 and #2, SFT follows up with a practical review of relevant aspects in fender manufacturing and curing in Paper #3 which precedes the concluding Paper #4 with a detailed report about testing.

The previous White Papers #1 and #2 (Compounding. A Winding Road and Mixing. A Step By Step Operation), emphasized the tremendous importance of the requirements for every individual fender project that make fender systems a tailor-made solution for every case and every scenario. **The conclusions that can be drawn in review of Papers #1 and #2 are the relevance of a fender's individualized rubber compound, the importance that a fender is endowed with the required physical properties for its specific field of application and that selecting the most suitable mixing device**

SFT Whitepaper Series:
#1 Compounding | #2 Mixing | #3 Curing | #4 Testing

for each production step plays a vital role in producing a high-quality fender.

The central theme throughout the series and discussions in the industry is the fact that only physical properties of a rubber compound have the highest correlation with quality and durability, and are based on internationally defined standards. Current international guidelines like PIANC2002, ASTM D2000, EAU 2004, ROM 2.0-11 (2012) or BS6349 (2014) refer exclusively to the physical properties of a rubber fender. Consequently, the durability of a fender and its physical properties are and will remain the defining goals of fender manufacturing which the SFT Group has committed its focus on.

SFT White Paper Series – #3.

Paper #3 of the SFT White Paper Series addresses a practical approach to a decisive, quality-critical step in the fender industry: Manufacturing and curing.

Manufacturing is the process of bringing the sheeted rubber compound into the shape of a fender by either using a mold, wrapping the rubber sheets on a pipe mandrel, or extruding the rubber through a die. The next step is curing, the process of hardening the rubber, i.e. transforming the rubber condition from plastic to elastic. Within a specified time frame, pressure and heat transform the non-vulcanized rubber into a cross-linked, three-dimensional molecular structure that gives the vulcanized product its outstanding final properties. While there is a wide variety of manufacturing and curing methods to choose from, the respective process needs to be adjusted to the fender type, its required performance, and the chosen compound. **A trust-worthy, experienced manufacturer will always prioritize the quality of the product and settle for the optimal method.**

This paper is divided into three sections that give an introduction (Section A) to the elements that have the most crucial impact in manufacturing (Section B) and curing (Section C) and concludes with consequences for a rubber fender that is incorrectly manufactured and/or cured.

A. Pressure, Temperature, and Time.

Before the various manufacturing and curing methods are discussed in detail, it should be mentioned that there are three main factors that influence every method: **Pressure, temperature, and time. The control of these three parameters is crucial in order to achieve a high-quality and durable rubber product.** A durable fender can only be manufactured at the exact pressure and right temperature within the correct amount of time – and this is even more important for high-performance fenders such as cone and cell fenders.

Pressure is differentiated between internal and external pressure, whereby both forms of pressure have a major influence on the final product.
Internal pressure results from the thermal expansion of rubber. External pressure is applied from outside using different mechanisms depending on the manufacturing method. Insufficient internal pressure leads to poor-quality products with low durability and a delamination of rubber sheets. Other defects such as extensive flow marks or insufficient bonding strength between embedded steel plates and the rubber can also occur. Some flow marks constitute a surface imperfection and are common in the industry. Extensive flow marks, however, can be a sign of inlying defects such as voids within the rubber body that cannot be detected by visual inspection. Such defects become obvious during break-in cycles and performance testing at the latest. If suitable internal pressure is applied during manufacturing and kept while curing, the risk of delamination, voids, extensive flow marks, and inlying defects is reduced considerably. The recommended pressure can vary between 2 MPa and 15 MPa, depending on the compound, the fender size, and the production method (see figure 1).

Just like pressure, **temperature** has an impact on the final product and is typically kept under 90 °C for manufacturing and between 100 °C and 150 °C for curing. **A step-by-step increase of the curing temperature is used which is very important to avoid heating up the compound to the**

maximum at once (see figure 2). Temperatures that are too low during the manufacturing process imply low fluidity of the rubber and without enough viscosity, the mold may not be completely filled which can cause major defects. Furthermore, too high temperatures while curing can lead to scorching, which is the term for premature vulcanization – it discolors and burns the rubber surface, leading to a damaged product. High temperatures are closely connected with the curing time. **In order to speed up the process of curing, some manufacturers compensate shorter curing times by higher temperatures which is not recommended because it can lead to defects or low-quality products.**

Curing **time** depends on the rubber thickness and the compound and ranges between several hours for small fenders and up to two days for large fenders. **The exact curing time for each rubber compound is individually determined and predefined after finishing the mixing process** (see White Paper 2, p. 12). Just like low internal pressure can lead to reduced bonding strength between embedded steel plates and the rubber, too long curing times can have the same effect. Too short curing times, even at the correct temperature, also lead to a low quality product, because the curing cannot be completed and the fenders will not provide the needed performance (see figure 3).

Pressure, temperature, and time have to be individually adjusted to the respective fender type, the required hardness grade and the fender size. Assessing the suitable parameters for the respective rubber product should be left to an experienced manufacturer since the consequences of incorrect handling can be severe.

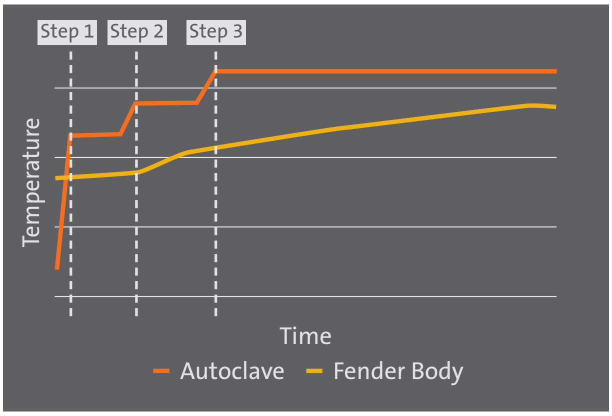


Figure 2: Temperature increase while curing

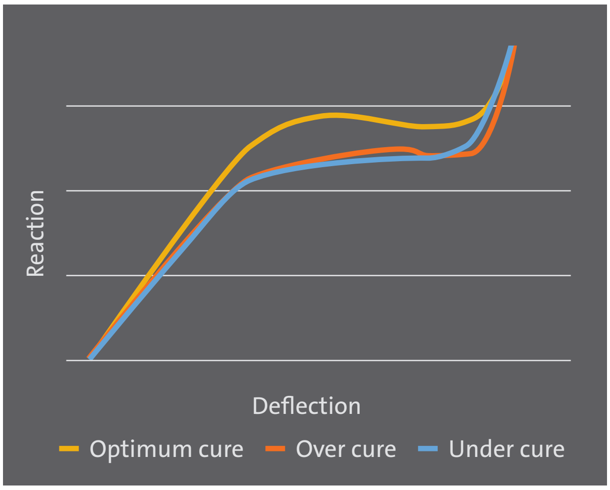


Figure 3: Impact of curing on performance

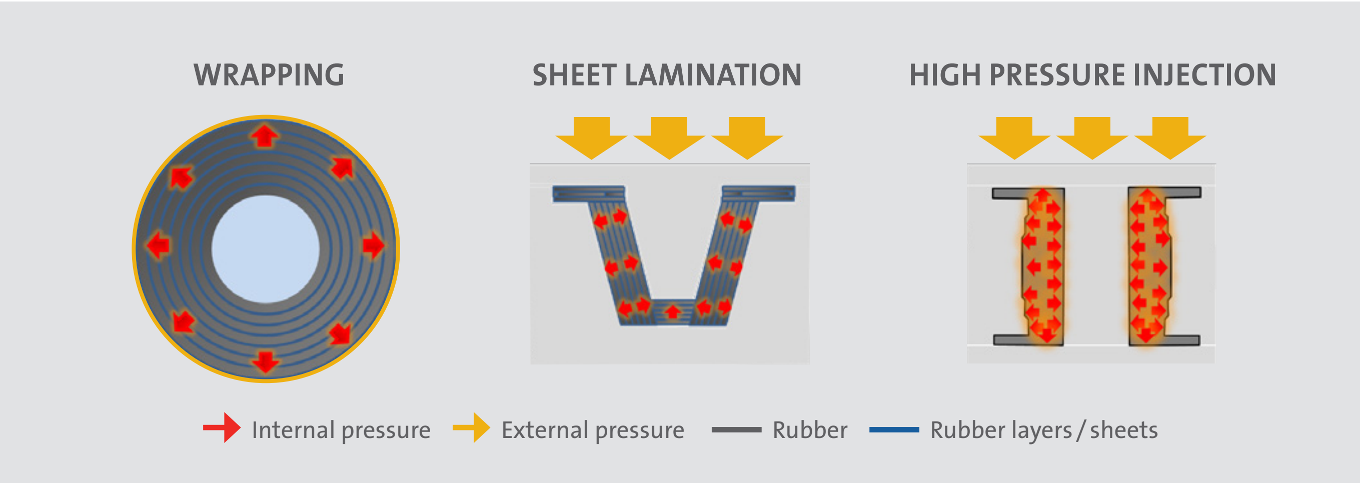


Figure 1: Internal and external pressure while curing

B. Manufacturing – Where the Magic Happens.

As discussed in the preceding SFT White Paper, the completed mixing process where the rubber blend, reinforcing fillers, process oil, and chemical additives are mixed with sulfur results in the unvulcanized, finalized rubber compound. The rubber compound is stored in uncut, folded sheets that are now facing the next crucial step of the manufacturing process: bringing it into the characteristic fender shape.

It should be noted that there is a variety of methods that can be used to produce the exact same type of a fender. **Nonetheless, not all methods result in the same quality which is why a well-versed manufacturer chooses the ideal procedure in order to achieve the highest possible product quality.** Furthermore, the method of choice for fender manufacturing is determined by the fender type, its required performance and thus its respective compound.

The most common manufacturing process for high performance fenders is inserting or injecting the compound into a mold. There are two types of molds, regular and jacket molds. Both consist of a cavity which is closed by a counterpart, whereas jacket molds have double outer walls in addition, to allow for a circulation of steam while curing. Each type can be locked by bolts to prevent the expanding rubber to open the mold. If bolting is not possible, molds need to be placed in a press while curing.

When a mold is used, it is necessary to fill the appropriate amount of rubber into the mold. If the filling is insufficient, the development of enough internal pressure is limited which causes a number of defects inside the fender, resulting in poor product quality. If too much rubber is filled in at once, the mold can not be closed completely, which results in high cost and possible damage to the equipment.

Other manufacturing methods are wrapping the compound around a pipe mandrel or extruding it through a die.

The overview on page 6 shows different methods used in fender manufacturing, addressing advantages, the fender types it is applied to, possible disadvantages, and particularities regarding pressure, temperature, and time.

Jacket mold with bolts during high pressure injection of rubber

Closing mold with counterpart prior to curing

MANUFACTURING METHODS

01 High Pressure Injection Molding

- ▶ High pressure injection molding is a highly efficient manufacturing process for regular and jacket molds, applied by modern and sophisticated producers. The mold is closed with its counterpart. Afterwards preheated rubber is injected into the mold with high pressure.
- ▶ Can generally be used to manufacture all kinds of molded fenders, especially suitable for cone fenders, cell fenders, and element fenders.
- + The amount of rubber that is injected into the mold using high pressure can be controlled exactly which leads to a more controllable production process.
- + Highly efficient, short production cycles, constant and uniform temperature and pressure throughout the process.

High pressure injection molding is a method that requires experienced operators and advanced equipment and process control technology for keeping the right pressure, temperature, and speed. However, if developed correctly and automatized, high pressure injection molding becomes an extremely efficient process that allows mass production with outstanding performance. Besides all other processes, high pressure injection molding has proven to be very successful and has developed into the method of choice for high-quality manufacturing.

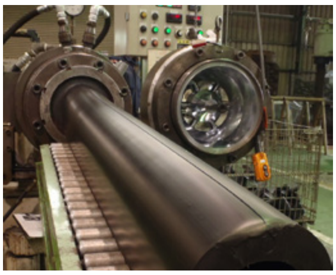
02 Compression Molding / Sheet Lamination Molding

- ▶ Next to injection molding one of the most common molding methods: preheated sheets are manually stacked into a mold which is then closed by its counterpart.
- ▶ Typically used for V Fenders.
- ▶ Limited pressure control in the mold therefore not suitable for certain products. The open mold requires an extra amount of rubber in order to be completely filled.
- + This method is simple and cost-effective in comparison to the other methods but can compromise quality and durability.

03 Wrapping

- ▶ Rubber sheets are wrapped around a pipe mandrel and piled on top of the other while the mandrel keeps rotating. This procedure is repeated until the required outer diameter and the desired shape is reached.
- ▶ Wrapping is usually used to manufacture cylindrical fenders. Molds are not needed for this method.
- − Pressure values are lower compared to other molding methods which makes it especially prone to wrinkling.
- − Not applicable for fenders with embedded steel plates.

04 Extrusion



- ▶ The rubber is extruded through a die that allows to create continuous fender profiles with a constant shape. This method uses much lower pressure than other manufacturing processes.
- ▶ Used to manufacture fenders like D, rectangular or other fender profiles.
- + Continuous and easily manageable flux provide shapes in any length.
- − Cannot be used for all rubber compounds.
- − Not applicable for fenders with embedded steel plates.

C. Curing – The Rubber Metamorphosis.

In this section, one of the most transforming steps in the fender production process is discussed: Rubber curing, also referred to as vulcanization.

Curing is the transformation of rubber from a plastic to an elastic condition using pressure and heat.

It can be compared to boiling an egg: rubber can only be vulcanized once and the transformation of a plastic to an elastic condition is irreversible.

The unvulcanized rubber compound contains sulfur and other additives which, through heat, initiate the vulcanization process. Within this process, the isolated rubber polymer chains create a three-dimensional cross-linked structure which is the basis for a performing rubber fender. **The rubber is subject to three-dimensional loading during every fender deflection, no matter which fender model, shape and geometry.** The volumetric structure that results from the three-dimensional arrangement also provides the fender with mechanical properties such as tensile strength, shear strength, and rigidity. **It needs to be pointed out that without curing, there is no functioning fender. The same is applicable to any other rubber product.**

During the curing process, the unvulcanized rubber is exposed to heat, usually in the form of steam, for a predefined, individual length of time. This takes place in a vulcanizer and sometimes with the help of additional external pressure. **The vulcanizer, also referred to as autoclave, provides a closed environment and is used for most of the curing processes.** Wrapped or extruded fenders are cured inside the chamber while for molded fenders additional external pressure is applied by an integrated press in the autoclave. This is done to either generate additional pressure to molds which are closed by bolts and thus achieving higher quality, or to close molds which cannot be locked by bolts.

Jacket molds do not need a vulcanizer as curing takes place inside the mold's double walls. Although most of the jacket molds are locked by bolts, they are put inside a press for additional pressure and higher quality.

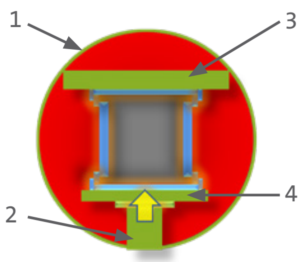
As for manufacturing, curing methods are determined by the fender type and curing parameters must be defined depending on the individual requirements of the fender project. Finding the optimal path that helps the manufacturer to achieve the highest quality is the key of curing and every other step in fender production.

Autoclave

Jacket mold with bolts

CURING METHODS

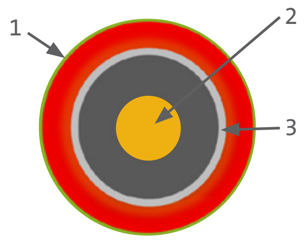
01 Autoclave use for molded fenders



1 Autoclave
2 Press
3 Upper Plate
4 Bottom Plate

- ▶ Molds containing non-vulcanized rubber are put in the closed chamber of the autoclave where they are exposed to steam while external pressure is applied onto the mold by the integrated press.
- ▶ Size limit for the usage of large molds, method cannot be used for very large fenders.
- + Correct temperatures and pressure values generated by the autoclave create the best possible physical properties and ensure a high product quality stability.
- + Easy process control.

02 Autoclave for wrapped and extruded fenders

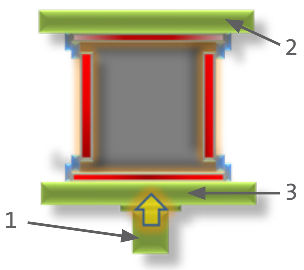


** Graphic shows wrapped fender*

1 Autoclave
2 Pipe Mandrel
3 Nylon strips

- ▶ The wrapped rubber sheets on the pipe mandrel are covered by wet nylon strips and are then cured in the autoclave. The nylon strips shrink when being heated and thus apply pressure on the rubber. The pipe mandrel is placed on a movable unit ensuring that the cylindrical shape is not deformed.
- ▶ Extruded fenders are cured inside the autoclave.
- ▶ No press function is used, therefore lower pressure than with the other methods which can lead to voids.
- – Prone to defects due to low pressure.

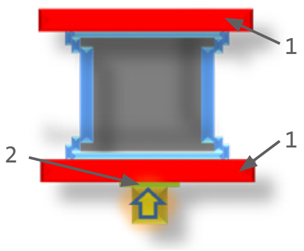
03 Jacket + Press



1 Press
2 Upper Plate
3 Bottom Plate

- ▶ For the curing process, steam is passed through the double outer walls to heat the rubber to the suitable curing temperature.
- ▶ The temperature and curing time of each part of the mold can be controlled independently, achieving a uniform heat distribution and reaching all parts of the fender.
- + Most suitable method for super large fenders to date but also available for smaller fenders.
- + Individual curing temperature control.

04 Hot Plate Press



1 Hot Plates
2 Press

- ▶ The press machine consists of a hot plate on the top and the bottom that each apply pressure and heat for vulcanization.
- ▶ Since heat only emanates from the top and the bottom, horizontal heat conduction is not ideal.
- ▶ For thick molds of large fenders, the heat dissipation is insufficient which is why this method is mainly used for small fenders.

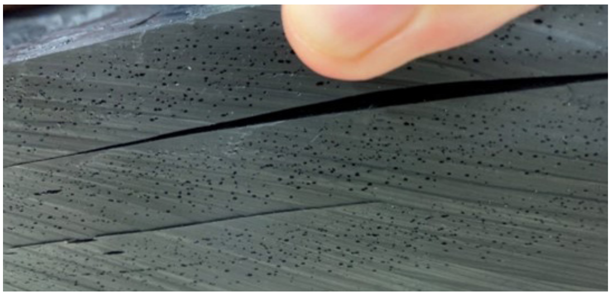
Equipment — Mold — Rubber — Heat

As mentioned before, there are several mistakes that can occur during the manufacturing and curing processes such as too low or too high temperature, too long or too short curing times, too low pressure, a mold which is not filled enough with rubber, or a combination due to inexperienced manufacturers and operators. The mistakes result in defects, sometimes interdependent, such as:

- Voids
- Delamination
- Surface defects such as extensive flow marks
- Insufficient bonding between steel plate and rubber

These defects all result in the degradation of the performance and decreased durability of the fender and ultimately an increased risk of accidents or downtime at the berths. If a rubber fender does not perform as required, safety in marine operations cannot be ensured.

Table 1 provides an overview to show the interaction of manufacturing and curing methods.



Delamination

Surface defect

Insufficient bonding

MANUFACTURING METHOD	FENDER TYPE	MANUFACTURING PROCESS	CURING METHOD
HIGH PRESSURE INJECTION	All kinds, most suitable for cone, cell, and element fenders	Rubber is automatically injected into mold	Autoclave or depending on size: jacket
COMPRESSION	Usually V Fenders	Sheets are manually put into a mold	Autoclave or Hot plate press
WRAPPING	Cylindrical Fenders	Rubber is wrapped around a rotating pipe	Autoclave
EXTRUSION	Fender Profiles, any lengths	Rubber is extruded through a die	Autoclave

Table 1: Overview Manufacturing and Curing methods

Conclusion.

Paper #3 of this series concludes that the relevance of manufacturing and curing in the fender industry cannot be stressed enough. Even if there are several ways of performing these two steps, it is in the hands of the manufacturer to choose the optimal processes. Pressure, temperature, and time are the decisive factors for achieving the best quality, especially regarding the prevention of the most typical defects in the final product. The incorrect handling of these parameters results in severe damages and fender failure during operation. **In a time and age where digital transformation and innovative technologies are becoming increasingly important, certain things simply cannot be automated or replaced: the practical know-how and experience of decades of accumulated knowledge in a complex industry like fender manufacturing.** As for the other procedures in the rubber fender industry, there is no "one size fits all" in manufacturing and curing as well. The complexity and the interdependency of the various steps rely on this type of know-how that has grown over time. As a fender manufacturer with extensive knowledge and unparalleled experience in rubber production, we at the ShibataFenderTeam Group recognise that all production steps, the choice of raw material, and the fender design are all interdependent and have to be individually chosen to esteem the uniqueness of each project. This truly holistic approach is one of our main responsibilities, fully committing to international standards and guidelines.

With our White Paper Series, we continuously advocate more transparency in fender production in order to ensure quality standards that are driven by a commitment to high-performance products and a clear sense of responsibility.

The final White Paper #4 on testing will detail different test methods to shed light on how the required physical properties of a high-quality fender are met.

References:
All references in this White Paper are quoted from:
- Abts, G. (2007). Einführung in die Kautschuktechnologie *(Introduction to rubber technology)*. München: Hanser
- Hofmann, W. & Gupta, H. (2009). Handbuch der Kautschuktech nologie. Band 3 Mischungsentwicklung und Verarbeitung (Reference guide to rubber technology. Volume 3 Compound development and processing). Ratingen: Gupta

Note:

- **High pressure injection molding creates higher quality products**
- **Pressure, temperature, and time are key to manufacturing and curing; these three parameters are related to each other**
- **Experience and practical knowledge are the fundamental factors in every production step**

ShibataFenderTeam Group.

The ShibataFenderTeam Group is a leading international fender manufacturer with 50+ years of group experience in fender production, +100,000 fenders in service, and 90+ years of experience in the production of rubber products. Shibata Industrial, headquartered in Japan, is responsible for production and R&D, while ShibataFenderTeam, headquartered in Germany, handles design and sales. Their regional offices in the US, Europe, and Asia are supported by a large network of well-established local representatives on six continents. Creating and protecting value – this is the essence of what our products are meant to do. We offer the full range of marine fender products, from simple rubber profiles to highly engineered systems, as well as accessories and fixings. Engineering excellence means that our partners can be confident in expecting the best from us in all areas. Our experience has earned us a reputation as a dependable partner in the international port, harbor, and waterways market.

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