WHITE PAPER #1

COMPOUNDING.

A WINDING ROAD

SHIBATAFENDERTEAM

on the safe side

Contents.

Executive summary.

The first part of the SFT White Paper Series on fender manufacturing outlines the considerations relevant to determining what makes a good fender. It focuses on the raw materials used in rubber production, the physical properties of a fender, and their correlation with the compound's composition.

There are international standards and guidelines providing guidance as to the physical properties of rubber fenders – like PIANC2002 and ASTM D2000. However, there is no international standard specifying the chemical composition of the rubber compound used in the manufacturing of rubber fenders.

The paper finds that in fender manufacturing, physical properties are the only reliable indicator of the quality of a rubber compound that is defined by international standards. In addition, it recommends that ratios of fillers and reinforcement agents such as carbon black (CB), calcium carbonate (CC) and silica should be determined by specialists with profound material knowledge, as amount and particle size greatly influence the compound as well as its performance and durability. The paper furthermore draws attention to the fact that rubber compounds mixed correctly with CC by experienced manufacturers comply with and surpass international testing standards.

SFT White Paper Series.

Safety, reliability, durability – the performance requirements of a fender boil down to these three aspects, and rightly so. **Fenders are meant to create a safe environment for ships and passengers while protecting port infrastructures and all personnel working there – reliably during the design life and beyond.** This is the ideal that ports and port operators strive for.

In this spirit, the four-part SFT White Paper Series aims to provide an unbiased view of what exactly makes a good fender – from source materials to manufacturing process.

Part I approaches this question by taking a closer look at the constituent components of a fender and their role in determining performance-relevant physical properties. Parts II and III detail the mixing and curing processes involved in producing a high-quality rubber fender. Part IV concludes the series with a detailed report about testing.

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

SFT White Paper Series – PART I.

As a reinforced rubber compound is the core of any fender, the first part of the SFT White Paper Series on fender manufacturing focusses on the raw materials used in rubber production, the physical properties of a fender, and their correlation with the compound's composition. Its goal is to detail the considerations relevant to determining what makes a good fender.

Yet, as straightforward as this might seem, when considering the product features required for such high performance, waters tend to become somewhat murky. There are international standards and guidelines – like PIANC2002, ASTM D2000, EAU 2004, ROM 2.0-11 (2012) or BS6349 (2014) – ensuring that fenders perform as designed when installed at a berth.

SPC Cone Fenders | IJmuiden | Netherlands

These standards provide guidance as to the physical properties of rubber fenders, among others compression set, elongation at break, and tensile strength. **There is, however, no international standard specifying the chemical composition of the rubber compound used in the manufacturing of rubber fenders.**

In other words, there are industry standards delineating a clear goal in the manufacturing of marine fenders, their performance, physical properties and durability, but there is no recommendation as to how to get there. The reason for this is simple: no two fender projects and no two fender manufacturers are alike. Each project has unique requirements that necessitate customized rubber compositions. In addition, not all polymers used in fender production are equally available in all parts of the world, requiring manufacturers to adjust their rubber compounds accordingly.

All of this provides a lot of room for market differentiation and opportunities for fender manufacturers to present their own best practice-approaches to producing high performance products. Yet, it has also become the breeding ground for some widely accepted – and by some stakeholders actively advocated – misconceptions about compound production, the most prevalent one asserting that the quality of a fender is primarily determined by the chemical composition of its rubber compound.

At the ShibataFenderTeam Group (SFT), we believe that the quality of a fender should be measured by its performance, i.e. by the degree to which a fender lives up to the requirements of its specific field of application.

The White Paper was conceived drawing on the expertise of the Deutsches Institut für Kautschuktechnologie e.V. (DIK), a German independent research institute specializing in polymeric materials and rubber technology, and of ASTM officials, as well as through previous discussions with polymer compounding specialists from the University of Gdansk, Poland.

A. Rubber compounds – the devil is in the details.

Typically, rubber fenders are made from a blend of polymers, e.g. natural rubber (NR) and synthetic rubber (SR), with fillers such as carbon black (CB), calcium carbonate (CC) and other additives to provide reinforcement and processability. **While there is a general consensus in the industry about most components used in fender production, ideas on the quality of the ingredients and their ratio diverge wildly from manufacturer to manufacturer – with some trying to establish generalizing views on the chemical composition of rubber compounds as a genuine quality indicator for the finished product.** A common misconception holds that the amount of the respective components in the rubber compound determines its quality. In the following, we will therefore take a closer look at the components constituting a rubber compound and their correlations.

Raw rubber material

Natural rubber (NR) is sourced in the form of latex from the Pará rubber tree (Hevea brasiliensis) in an area approximately 15° north and south of the Equator, with Southeast Asia being the main producer worldwide. About 40 % of worldwide rubber consumption is based on NR, which is traded as a commodity on stock markets. The geographical limitation of NR's availability and its shortage at the beginning of the 1900s led to the development of synthetic rubber (SR) in other parts of the world. Well-known and frequently used are styrene-butadiene rubber (SBR), ethylene propylene diene monomer rubber (EPDM), or neoprene. Of all the SRs, SBR is the one most frequently used for fender compounds.

SBR is a copolymer of styrene and butadiene which can be polymerized in any ratio. It is derived from petroleum byproducts and dependent on the price of cruide oil and NR. About 60 % of worldwide rubber consumption is based on SRs.

NR- and SBR-only compounds differ in their characteristics as well as their impact on compound processability, fender performance and its physical properties.

Natural Rubber (100 % NR compounds)

+ well-reinforced by nature
+ large stretch ratio (elongation)
+ high resilience
+ extremely waterproof

– poor aging properties
– poor oil resistance
– susceptible to reversion (therefore sensitive to vulcanization)
– sensitive to ozone cracking
– as a natural product and due to the natural sourcing process, it contains impurities like protein, ash,* dirt (leaves, dust)

* Roberts, A. D. (1990). Natural rubber science and technology. Oxford: Oxford University Press

Synthetic rubber (100% SBR compounds)

+ good abrasion resistance
+ good aging stability

– inherently poor tensile strength
– poor heat aging resistance
– more difficult to process

In comparison, while SBR in its pure state is less sticky and has a higher density and glass transition temperature than NR, it also has a lower modulus and tear resistance, and needs additional reinforcement and a higher amount of softeners. NR, by contrast, is well-reinforced from the outset.

Thus, rubber compounds with either NR or SBR as the only polymer have strong limitations, and therefore the industry usually uses blends of NR and SBR to harness the advantageous properties of both. If specifications require 100 % NR or SBR compounds, specifiers should make sure they are familiar with the problematic nature of these materials, since a wrong approach here could put a berth in jeopardy and could lead to substantial liability claims for the specifier.

The choice for – and the amount of – NR or SBR in the blend determines the amount of other components to be added to improve the properties of the compound, the best-known ones being carbon black (CB) and calcium carbonate (CC). The ratio in which polymers are mixed with these components defines the chemical composition of the rubber compound. Detailing the proportional relation between all components in the compound has limited informative value regarding the quality of a fender. **Two rubber compounds can differ in their chemical compositions but still have physical properties that meet or exceed the requirements of international standards (see also Table 2).** Nonetheless, it has become a commonplace for some stakeholders to argue that the presence and amount of the respective components in the compound serve as a quality indicator. A closer look at the two fillers CB and CC shows that such generalizing statements are misleading.

B. Carbon Black – essential in measures.

Carbon black (CB) is a well-established reinforcement for rubber compounds available in different particle sizes. Its capabilities are dependent not only on its amount in the rubber compound but also on its grade and particle size. Its effect can best be measured by examining the development of e.g. tensile strength when gradually increasing the amount of CB. Figure 1 illustrates how the tensile strength of the compound increases upon adding CB up to a breaking point. After reaching that critical stage, tensile strength decreases, as there is not enough rubber left to disperse the CB particles, meaning the compound is overloaded with CB.

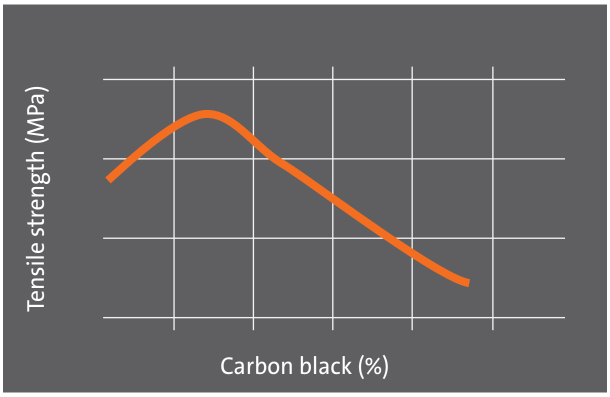

Figure 1: Typical influence of CB on tensile strength in NR compounds

This example supports the fact that the amount of CB is indeed important, but in moderation and depending on the rubber used, as NR needs less reinforcement than SBR. In other words, when it comes to the amount of CB, more is not always better. Thus, to ensure the desired compound quality, the CB concentration has to be chosen carefully at an early stage of the production process, keeping in mind all relevant factors.

On a side note, gray fenders do not contain any CB at all. As gray pneumatic, extruded and tug boat fenders make direct contact with the vessel, end-users require them to be non-marking. Since adding CB would inevitably result in a black rubber compound, they contain silica as reinforcement. And yet they comply with the same rigorous testing standards as high-durability black fenders intended for +20-year service life. **This shows again that the quality of a fender cannot be determined by the amount of CB in its rubber blend.**

Gray Pneumatic Fender | Karlskrona | Sweden

The particle size of CB is another influencing factor relevant in fender production, and much discussed in research. **It has been proven that the larger the average particle size of CB, the lower the modulus of the rubber compound, a fact supported by a great number of studies and tests.** Low modulus means that there is little force required to stretch (elongate) a specimen, which is indicative of a low-quality compound. Tests performed by Shibata Industrial in Japan prove how modulus in both NR- and SBR-only compounds with a constant dose of CB changes depending on the filler's particle size. Comparing the effects of using CB with an average particle size ranging from 22nm to 78nm, compound modulus dropped significantly the larger the particles became. Over the entire measuring range, modulus dropped by approximately 30 % with 100 % NR compounds and almost 50 % with 100 % SBR compounds (see Figure 2) – a difference incidentally proving a fact that was discussed earlier, that NR requires less additional reinforcement.

In summary, the quality of compounds cannot be gauged by their amount of CB. Compounds should therefore not be excluded from specifications only based on these grounds. The compound's component ratio and the necessary CB particle size are unavoidably bound up with a fender's desired performance and physical properties. A similar reasoning holds true for the use of CC in rubber compounds.

CB GRADES	ISAF N220	HAF N330	FEF N550	GPF N660	SRF-LM
Average particle size (nm)	22	28	45	66	78
NR 300 % modulus (MPa)	16.1	15.5	15.7	13.3	10.8
SBR 300 % modulus (MPa)	10.3	9.7	8.8	6	5.4

Table 1: Modulus vs. CB grade

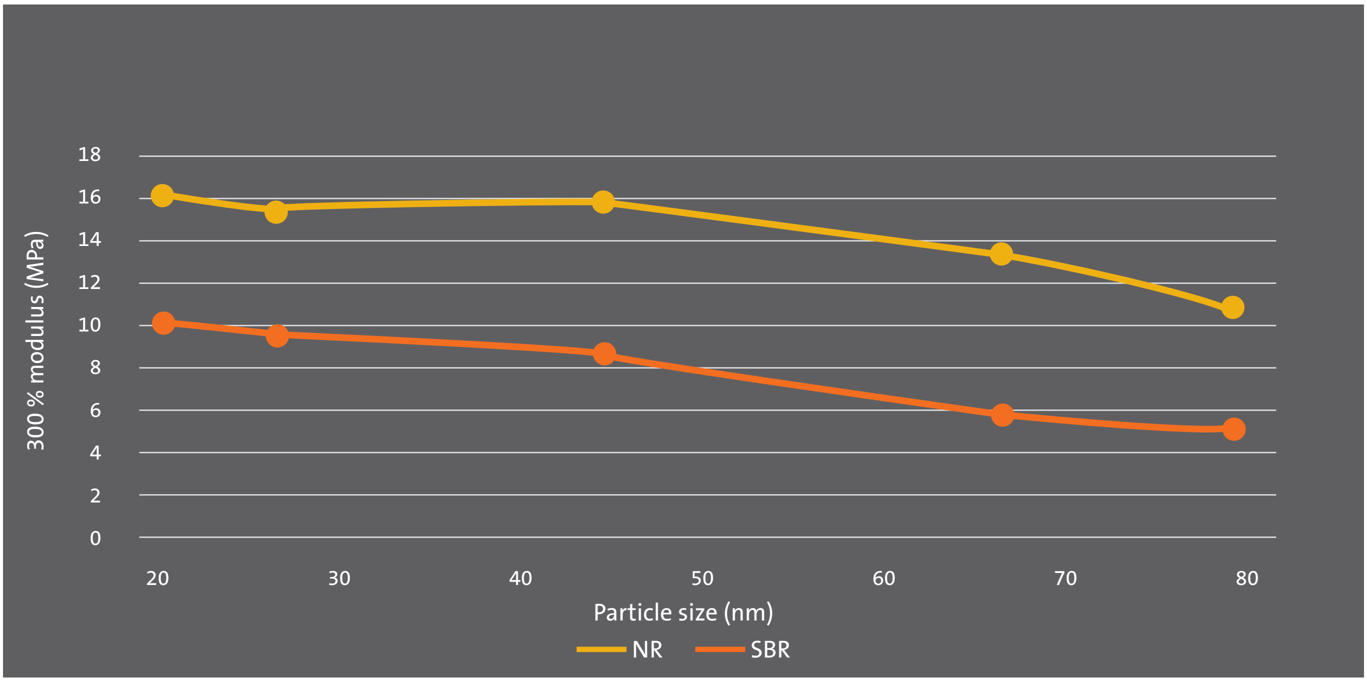

Figure 2: Modulus vs. particle size of CB (CB 33 %)

C. Calcium carbonate – better than its reputation.

Apart from CB, high-quality rubber products across the industry and beyond use several other fillers, of which calcium carbonate (CC) is the best-known. There are two different kinds of CC: natural CC and synthetic CC.

Both come in powder form, though particle sizes may vary. Adding CC enhances processability and improves behavior during vulcanization, and compression set results. Also, the right amount of synthetic CC in small particle sizes has a distinct reinforcing effect.

Despite these merits, CC has a rather bad reputation in the market. It is said to be a cheap replacement for polymers, and that it leads to poorer physical properties as well as reduced performance and durability in rubber compounds. Depending on the case, these claims might be correct; they do not, however, provide the full truth about CC.

As with CB, the origin, grade, dispersion, and above all the particle size and purity of CC determine how the filler influences the physical properties and durability of the rubber compound. Therefore, it cannot be generalized that CC only has negative effects. Used correctly, it is helpful in giving a compound physical properties that meet or even exceed international testing standards for rubber fenders.

The experts of ASTM and other institutes are unanimous in their opinion that:

> *“When it comes to rubber compounding for marine fenders, there is no standard regarding the chemical composition, as these fenders’ quality is determined by their capacity to live up to the rigid performance requirements of their field of operation. As a consequence, the compound’s physical properties are to be regarded as the only meaningful indicator of a rubber fender’s product quality.”*

CSS Cell Fenders | Yamal | Russia

D. The right compound – a winding road.

Summarizing what we have seen so far, Table 2 vividly illustrates that two rubber compounds can have very different chemical compositions and still possess the necessary physical properties to comply with required performance criteria for marine fenders, and thus meet international standards. The most important reasons for this are the different reinforcement requirements of NR and SBR. **The choice of the rubber base of the compound is dependent on the polymer's availability and the product features required in the fender.** The same causal logic also applies to the choice and amount of the other components that the rubber compound is mixed with.

As plausible as this might sound, it has become a recurring phenomenon in the fender industry to distract from this simple truth while disseminating misleading information. In this respect, wrongly asserting that the chemical composition of a rubber component is a fender's foremost quality criterion puts a dangerous spin on the facts. **Chemical composition is important in fender production, but not everything. As shown earlier, it is the physical properties that ultimately determine the quality of a fender.**

Such distortion of facts becomes problematic when subjective criteria are invoked by stakeholders as a quality indicator for fenders. A rather benign example of this concerns the density of rubber compounds. High density is considered a symptom for low quality – which is a problematic assertion when accepted without question.

CHEMICAL COMPOSITION – TGA TEST

	COMPOUND 1	COMPOUND 2
Polymer [%]	47.5	46.9
Carbon Black [%]	37.5	27.5
Residues (Ash) [%]	2.9	17.9

PHYSICAL PROPERTIES – PHYSICAL PROPERTIES TEST

PROPERTIES	TEST METHOD	SPECIFICATION	RESULT COMPOUND 1	REMARK	RESULT COMPOUND 2	REMARK
Tensile Strength [MPa]	ASTM D412 Die C – original value before ageing	≥ 16	20.20	✔	19.11	✔
Elongation at Break [%]	ASTM D412 Die C – original value before ageing	≥ 400	514.00	✔	586.08	✔
Tear Resistance [kN/m]	ASTM D624 Die B	≥ 70	127.34	✔	104.42	✔
Compression Set [%]	ASTM D395 Method B – at 70°C for 22 hours	≤ 30	19.31	✔	17.93	✔

Table 2: Compound comparison regarding chemical composition and physical properties | Compound 1 and 2 taken from fenders that have been successfully operational for years

As components like fillers and vulcanization agents have a higher density than rubber, any compound needing reinforcement is likely to have a higher density. And, as we saw earlier on, such compounds also comply with international standards. **So density is only a meaningful parameter when considered in context.**

A most striking example of this type of deception is the practice of assessing the quality of a rubber compound by subjecting it to thermogravimetric analysis (TGA).

TGA is a method of thermal analysis in which a sample – in this case of a rubber fender – is continuously weighed during heating. As different components burn off at different temperatures, the loss in weight provides an indication of the sample's composition. Certain parts, however, do not burn, even at very high temperatures and despite the addition of atmospheric oxygen. Others are released as CO_2 during the process. The non-burning parts remaining at the end are known as residues (ash).

While TGA is useful as a practical means of verifying the chemical composition of a compound, it does not provide any meaningful correlation to the quality of the compound.

Nonetheless, a high percentage of ash is erroneously considered by some as an indicator of low quality – even though there are perfectly logical reasons for residues.

As mentioned earlier, NR as a natural product contains ash, so it is not surprising that higher amounts of ash remain after burning an NR-based rubber compound. Another residue, zinc oxide, is commonly added for the curing process as a necessary vulcanization additive. Silica, which is the reinforcement agent for gray fenders (see also p. 5), does not burn either, and larger amounts of ash remain. The same applies to the aforementioned CC.

Using TGA results to discredit components that are typical in rubber production – essential even in fender manufacturing in order to meet certain requirements – must be seen not only as a misleading practice, but also as a potentially dangerous one. As mentioned before, TGA results do not allow any meaningful conclusions as to the quality of a fender or its suitability for a project. Thus, TGA results do not ensure that a fender lives up to what is expected in its field of operation. **And if a rubber fender does not perform as required, safety in marine operations cannot be ensured.**

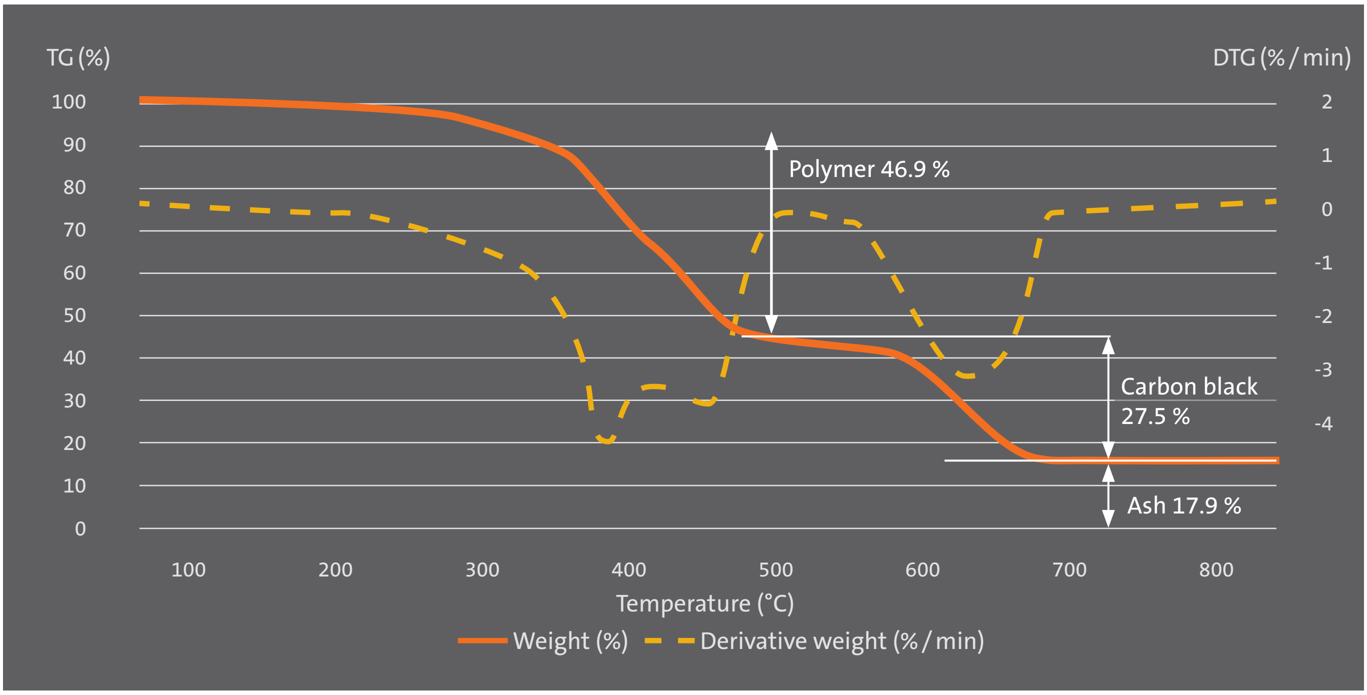

Figure 3: Thermogravimetric analysis (TGA) | Values based on Compound 2 (see Table 2)

After all, fenders are of paramount importance in securing port structures and creating a safe environment for ships and crews. Against this background, we believe that the answer to what makes a good fender not only has to reflect a high level of technical expertise, but also give evidence of a clear sense of corporate responsibility.

From the technical point of view, a good fender is the result of a combination of high-quality source materials and a fender manufacturer expertly skilled in compounding, thereby guaranteeing that the performance of the final product meets – if not exceeds – individual project requirements, and also international standards. From an ethical perspective, a good fender is the physical evidence of a corporate culture that puts the individual performance requirements of the customer first in determining product quality, and not its own need for market differentiation. In a nutshell, the quality of a fender is determined by its performance in the field, not by a fender manufacturer's claims.

As a fender manufacturer with extensive knowledge and unparalleled expertise in rubber production, we at the ShibataFenderTeam Group (SFT) believe that compounding is an expert discipline not to be taken lightly, and so project-specific that it cannot be generalized in any way. **In the end, a marine fender needs an individualized rubber compound endowing it with the right physical properties for its specific field of application.** With its white paper series, SFT wishes to 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.

ShibataFenderTeam Group.

The ShibataFenderTeam Group is one of the leading international fender manufacturers 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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References:

Unless indicated otherwise, all references to rubber and rubber compounding 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 Kautschuktechnologie *(Reference guide to rubber technology)*. Ratingen: Gupta

Note:

- **Physical properties are the only reliable indicator of the quality of a rubber compound that is defined by international standards.**
- **Ratios of fillers and reinforcement agents like CB, CC and silica should be determined by specialists with a profound material knowledge, as amount and particle size greatly influence the compound, its performance and durability.**
- **Compounds mixed correctly with CC by experienced manufacturers comply with and surpass international testing standards; fenders from such compounds have a high durability and achieve a typical service life of 20+ years.**

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WHITE PAPER #2

MIXING.

A STEP BY STEP OPERATION

SHIBATAFENDERTEAM

on the safe side

Contents.

Executive summary.

The second part of the SFT White Paper Series on fender manufacturing follows up on the first part with an overview of the rubber compound's mixing process. Based on the results on rubber compounding shown in the previous paper, the following section of the series focuses on the preparation and blending steps of the raw materials and how they impact the performance of a rubber fender.

Fender manufacturing – like other rubber manufacturing sectors – is generally known as an industry that mostly relies on practical knowledge and experience. The complexity and the infinite number of possible rubber compound compositions and various mixing techniques, as well as individual requirements for each different rubber product, make it difficult to determine unifying procedures.

This paper outlines the individual steps of rubber mixing in order to create an insight in this very sensitive part of fender manufacturing. By examining the complex interaction between materials and their processing, and presenting the various available mixing devices, it becomes clear to which extent high-quality fender production depends on the expertise of the manufacturer. Choosing and properly operating the equipment is subject to long-standing experience in this significant part of rubber manufacturing and its effects on the final quality of the fender.

SFT White Paper Series.

Marine fender systems are essential when it comes to protecting people, ships, port infrastructure and creating safe berthing operations. The quality of a marine fender is exclusively measured by its performance properties which boil down to three aspects: Safety, Reliability, Durability.

Nevertheless, requirements for each fender system are different, which is why the development of a fender is a unique process from designing and engineering the customized solution to choosing raw materials through to the manufacturing procedures.

Current international standards and guidelines like PIANC2002, ASTM D2000, EAU 2004, ROM 2.0-11 (2012) or BS6349 (2014) merely refer to the final physical properties of a marine fender. They do not indicate specifications on the chemi-cal composition, just as there are no industry regulations for mixing and the equipment used in the procedure. **Consequently, the quality of a fender and its physical properties are and will remain the defined goal of fender manufacturing.**

Masterbatch cut and stacked for finalization

This four-part SFT White Paper Series explores the entire process from rubber compounding to testing the final rubber fender in order to provide an unbiased view of what exactly makes a high-quality fender. It features examples of how the performance-relevant physical properties can be achieved in each production step.

Part I covers the correlation of raw materials and their composition with the properties of the final fender. Part II details important aspects of the mixing process and the corresponding equipment. Part III delineates the manufacturing and curing process and the series closes with a detailed report about testing in Part IV.

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

With its White Paper Series, SFT wishes to 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.

SFT White Paper Series – PART II.

Since mixing is an essential step in the production of rubber products, this part of the SFT White Paper Series focusses on the individual phases of the mixing process and how they impact the performance of a rubber fender. Rubber processing requires thorough incorporation and dispersion of the compounding elements, such as different types of raw rubbers, fillers, and various chemicals. **It is vital to pay attention to how these elements come together and make a high-quality fender.** Superior mechanical strength, flexibility, and durability are some of the requirements that play a crucial role in the life of a fender. **There is a mutual dependency between all steps of fender manufacturing from choosing the raw materials, balancing out the compound design, up to the accuracy of the mixing process that yield the predefined final product.** The development of the compounding recipe and the subsequent mixing process are the most sensitive parts when it comes to fender production.

The extensive variety of rubber compound compositions requires the mixing process to address these differences in terms of process and equipment. **Considering that no two fender projects are alike, the individuality in the production process for each different project is essential.**

The complexity of interaction between composition and product properties demands profound knowledge and a history of expertise on the manufacturer's side – which traditionally evolves and matures through long-term experience in this field.

Raw natural rubber

Rubber processability, process reliability and economic efficiency are characteristics which can be achieved in a number of different ways. **In order to obtain a homogeneous distribution of the compounding ingredients and a high dispersion, the manufacturer depends on high-performance industrial mixing equipment.** The paper will hereinafter highlight the appropriate equipment for each production step and comment on some widespread misconceptions regarding the different types of mixers commonly used in the rubber industry.

This White Paper demonstrates the rubber mixing process (consisting of mastication, masterbatch production, and finalization; see figures 1 and 2 for an overview and the detailed steps) and the equipment as it is advocated by the ShibataFenderTeam Group (SFT) in order to demonstrate an example for the industry.

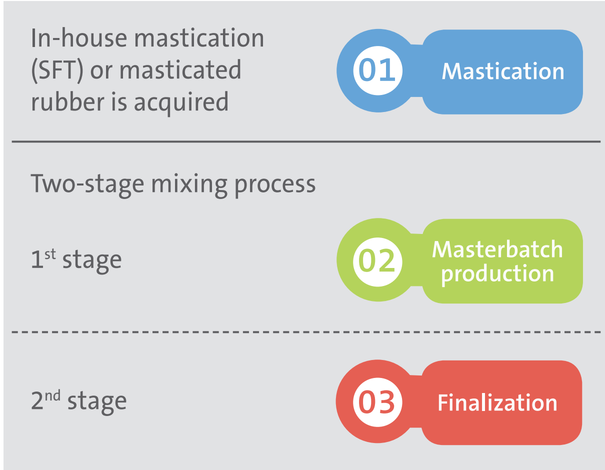


Figure 1: Mixing process – Overview

Note:

The following procedure illustrates a two-stage mixing process which by no means claims to be the single pathway to producing a good fender. It does, however, show the correlation of the various steps of the mixing process and the factors to be taken into account for the final quality of a fender. Single-stage mixing in internal mixers is possible, as well as using just one type of internal mixer, although that is not an ideal solution for all rubber compounds.

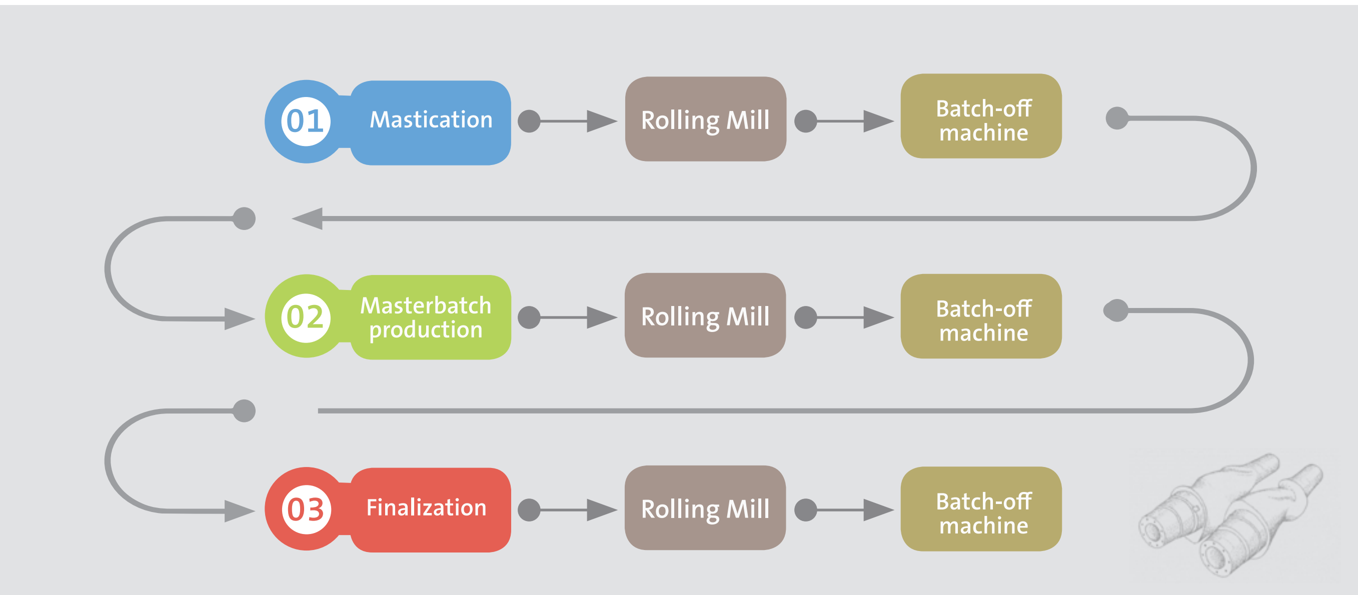


Figure 2: Mixing process – Detailed steps

A. Compounding Ingredients – Fundamental Choices.

As discussed in Part I of this series, a well-considered chemical composition of the rubber compound is the cornerstone to a high-quality fender and favorable mixing behavior. In avoidance of inconsistencies in the product's final properties, the selection of raw rubber is particularly important. The initial condition of natural rubber (NR) as a natural product can vary in viscosity due to varying molecular weight and uneven molecular distribution. NR is sourced in the form of latex from a tree called Hevea brasiliensis. High consumption and the geographical limitation of this raw material in the 18th century lead to the development of synthetic rubber (SR). The most frequently used synthetic rubber in fender compounds is styrene-butadiene rubber (SBR). Today, it has become standard to blend NR with SR which, due to the various complementary properties of different rubber types, has an enhancing effect on the fender's physical properties like aging stability, tensile strength and processability. **Depending on the composition of the rubber blend, the other compounding ingredients have to be balanced very precisely in order to obtain the optimal features of the final rubber fender.** Additional

Synthetic rubber (Styrene – butadiene rubber)

ingredients to enhance the required physical properties of the fender, as well as the processability of the rubber, are carbon black (CB), natural and synthetic calcium carbonate (CC), process oil, antioxidant and antiozonant to protect the rubber against aging and ozone deterioration as well as sulfur as a vulcanizing agent. **The chemical interaction and the reciprocal influence between the individual elements must be considered accurately for every rubber composition.** As mentioned before, the number of possible formulas is infinite and its composition a matter of precision to the gram. Detailed information on the individual compounding ingredients and rubber compounding can be obtained from Part I of the White Paper Series.

Masticated natural rubber

B. Rubber Mastication – Pivotal Preparation.

Natural rubber in its original form possesses a very high molecular weight (which equals high viscosity) and an uneven molecular structure – a condition that complicates homogeneous blending with synthetic rubber as well as uniform dispersion with other ingredients. For this reason, mechanical mastication (see figure 3) is conducted prior to the actual mixing process in order to obtain a material surface that is receptive to dispersion of polymer blend and compounding ingredients.

During the mechanical mastication process, the shearing forces of the rotors in an internal mixer break down the rubber's molecular structure, shorten the long molecular chains and produce a parallel alignment of the molecules. The result is a low viscosity rubber with uniform plasticity and flowability – and thus being a raw material with ideal mixing properties and processability. **Rubber manufacturers can choose to acquire masticated rubber or to perform in-house mastication (as done at SFT), which provides additional opportunities for quality management and in-batch as well as batch-to-batch uniformity.** Mastication is usually done with internal mixers (for further information on mixers, see following section about mixing equipment). When using an internal mixer, the natural rubber enters the mixing chamber through the hopper door in block form and is processed by the two heavy steel rotor paddles of the mixer. The masticated rubber is discharged and directly dropped onto a rolling mill, where it is sheeted for further processability (see figure 4). All steps from masticating to finalization are monitored and documented precisely.

Masticated rubber on rolling mill

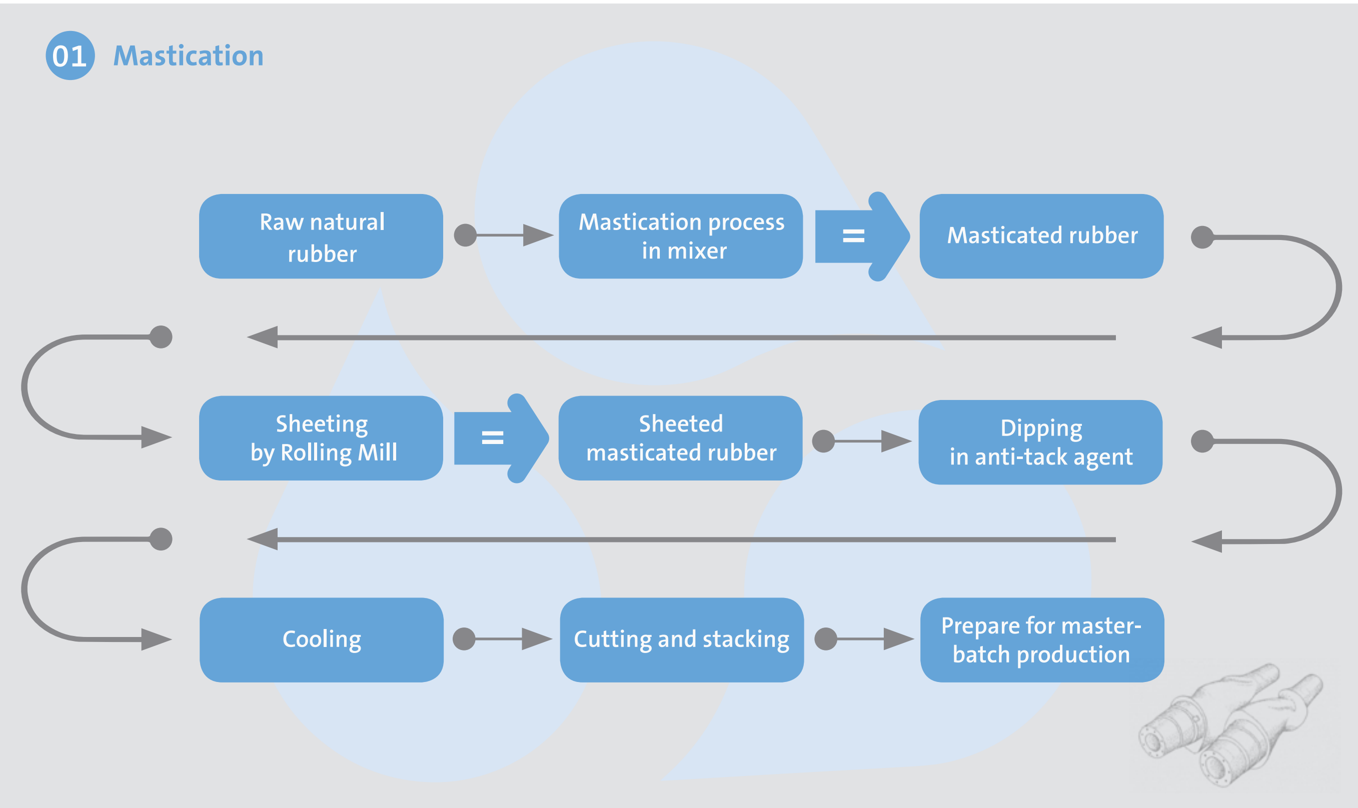
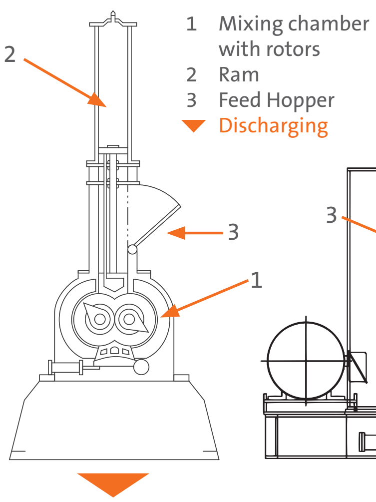


Figure 3: Mastication – Detailed steps

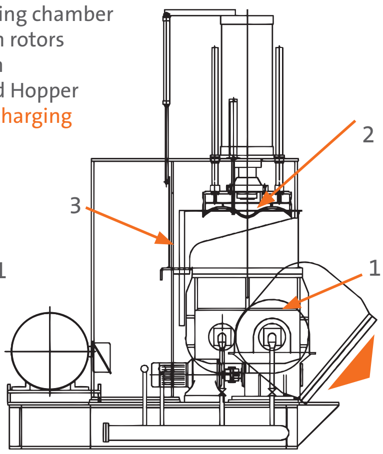
C. Mixing Equipment – Effective Machine Teamwork.

The most common mixers in rubber manufacturing are the Banbury and the Kneader, both internal mixers, and the rolling mill. **The construction of these two internal mixers is similar in regard to their mechanical characteristics, whereas each machine has its preferences for different procedures, and they can be used complementarily for optimized time and cost efficiency.** Both mixers basically consist of counter-rotating pairs of rotors, a mixing chamber, a floating weight (ram), and a feed hopper. The two mixers have different rubber output mechanisms: the rubber exits the Kneader directly from the mixing chamber, which is tilted backwards in order to discharge the material. The Banbury has a drop door, through which the rubber is dropped onto the rolling mill.

Both machines are available in different chamber sizes. **Contrary to popular industry belief, a large mixer is not directly linked to a more efficient process or a high quality of the final outcome:** with thermally sensitive polymers such as NR and SBR, a certain temperature should not be exceeded during the mixing process. The key advantage of smaller mixers is a more favorable chamber volume to cooling surface ratio. Smaller mixing systems have a superior surface-cooling ratio compared to larger systems: The volume increases in the cube, whereas the cooling surface increases in the square. Consequently, the mixing temperature will always be considerably higher in a larger mixer. Furthermore, in larger mixers it takes longer to mix the large batches, which can damage the rubber's molecular structure and can harm the quality of the final compound. The quality decreases with extended mixing time and finally negatively affects the physical properties of the final product. **As a matter of fact, a larger mixer is economically beneficial due to its higher output rates, but following the principle of quality as a priority, a middle-sized mixer should be the first choice to put quality over quantity.**



Drawing of a Banbury mixer



Drawing of a Kneader mixer

Banbury mixer

Kneader mixer

Despite the similarities of both internal mixers, each machine provides certain benefits that make it more suitable for one production step than another (for a detailed overview see table 1). The Banbury is the superior mixer for masterbatch production with its high-performance engine, adjustable rotor speed, and automated weighing system. High degrees of dispersion and mixing high viscosity rubber can be achieved within a short time frame. Since the Banbury operates at higher temperatures than the Kneader, it is not the best solution for mastication and finalization, although it is possible. The higher temperature of the Banbury is compensated by a shorter mixing time. However, there are certain advantages to favor the Kneader over the Banbury.

These are:

- Mastication: ease of loading raw rubber blocks
- Masterbatch production: to produce colored compounds, like grey compounds, since the mixing temperature needs to be relatively low
- Finalization: greater cooling effect and the ease of material discharging from mixing chamber

Selecting the right mixer for the respective production step and its correct operation requires a lot of experience; using both mixers can be a huge advantage.

The rolling mill consists of two parallel, counter rotating rolls with a gap in between that can be adjusted. The rolling mill can be used for all steps of the mixing process. For the masterbatch production other compounding ingredients are added into the rubber. The extremely high shearing forces of the rolling mill at a low temperature lead to superior dispersibility of the ingredients, but unlike the internal mixers with their sealed chambers, the rolling mill is an open mechanic system and the raw materials would scatter.

Rolling mill

This would create a dusty and unsafe production environment, which is a strong argument for the use of internal mixers. Additionally, a longer mixing time reduces the efficiency of the rolling mill and it is therefore most commonly used for sheeting, which will be described in the following section.

MIXING STEP	INTERNAL MIXERS		ROLLING MILL
	BANBURY	KNEADER	TWO-ROLL MILL
Mastication 01	+ possible but less efficient	+ efficient filling of rubber blocks	+ superior shearing forces – comparatively low productivity
Masterbatch production 02	+ suitable for high viscosity rubbers + adjustable rotor speed + rapid dispersion + sealed chamber + automated weighing + temperature is suitable for chemical dispersion	+ sealed chamber + suitable for colored compound due to lower temperature – lower productivity than Banbury – not suitable for high viscosity rubbers	+ high shear force and very thorough dispersion – comparatively low productivity – raw materials scatter – requires skilled worker – hazardous work environment
Finalization 03	+ possible but less efficient	+ greater cooling effect + easy discharge of material	+/– see above

Table 1: Mixing equipment at a glance

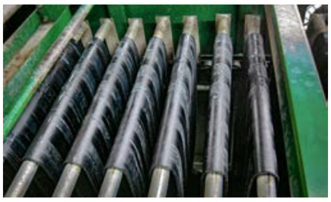
Masterbatch on rolling mill

D. Sheeting – Creating Uniformity.

After each mixing operation (mastication, masterbatch production and finalization), the rubber is prepared for the next production stage by being sheeted on a rolling mill. **The rubber that is dropped into the gap between the milling rolls is once again mixed by the counter rotating rolls and high shear forces.** The rubber then wraps around the front roll and is transformed into a sheet by the two milling rolls. Next to the rolling mill the batch-off machine is placed. It executes four main steps with a rotary cutter at the end of the line (see figure 4). First, the rubber sheets are embossed with the compound code (masterbatch and finalized compound only) and immersed into a container filled with a diluted anti-tack agent which prevents the uncured rubber sheets from sticking together. The rubber sheets are then transferred to a cooling chamber which quickly decreases their temperature and also helps to dry the anti-tack agent. Finally, the rubber is transferred to the rotary cutter where the sheets are cut into the desired length. The finalized rubber remains uncut and is folded in one piece, in order to improve processability for the following manufacturing process.

Embossing

Anti-tack



Cooling

Cutting

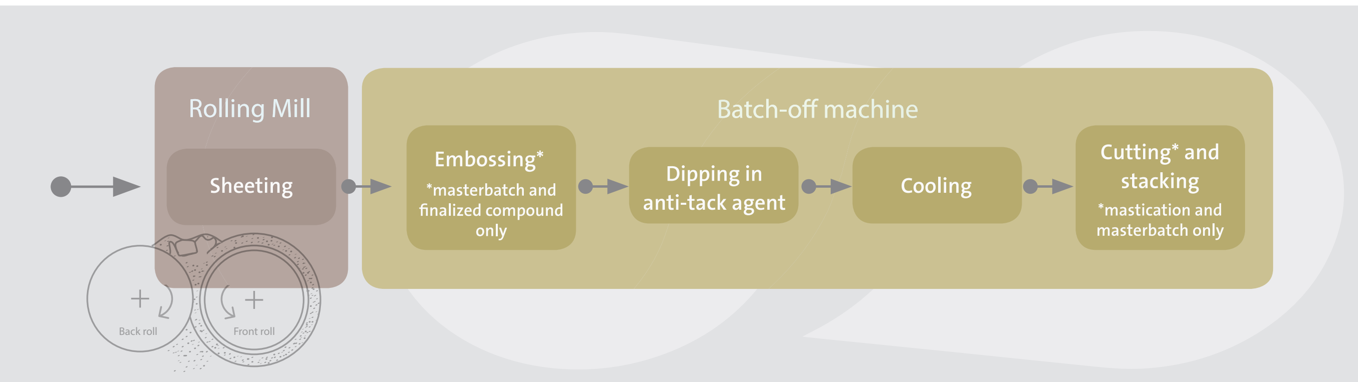


Figure 4: Mixing process – Rolling mill and batch-off machine

E. Masterbatch – All about the Additives.

The two-stage mixing process starts with the production of the masterbatch: a crucial step in the mixing process, preferrably operated with the Banbury (see figure 5). This is where all compounding ingredients except for the vulcanizing agent are mixed. **Special attention has to be paid on the sequence of ingredient addition and the subsequent mixing times.** In a first step, masticated natural rubber (NR) is mixed with synthetic rubber (styrene-butadiene rubber, SBR) to create a uniform rubber blend. Due to the natural rubber's properties obtained through mastication, the rubber blend can be optimally mixed with all the fillers and chemicals required for the desired physical properties. Carbon black and process oil are added in a second step and after the set mixing time, fillers and chemicals are released into the chamber. After every addition of an ingredient, the hopper door is closed again and the material is pressed into the chamber by the ram, where it is then mixed under accurate surveillance of temperature development and rotation forces.

There are several parameters that have to be monitored accurately in this operation. For a start, the automated weighing system and the auto mixing process controller of the Banbury prevent human errors regarding the chemical composition of the compound and the mixing settings. **If the mixing is insufficient at this stage, carbon black is not dispersed homogeneously which negatively affects the final compound.** Mixing has to be conducted at a relatively high temperature in order to melt the chemicals for sufficient dispersion. Whereas with too high temperatures, the rubber becomes too soft and sufficient shearing forces cannot be generated, which subsequently leads to poorer ingredient dispersion. Besides, NR & SBR do not have a high temperature resistance so too high temperatures will negatively impact the physical properties of the compound. **This fine temperature balance calls for close monitoring of the mixing speed and time.** Furthermore, the Banbury is equipped with a highly efficient cooling system which helps to control the temperature throughout the procedure. The masterbatch is then once again processed by the rolling mill and the batch-off machine and will be stored for a cooling period before it is further processed.

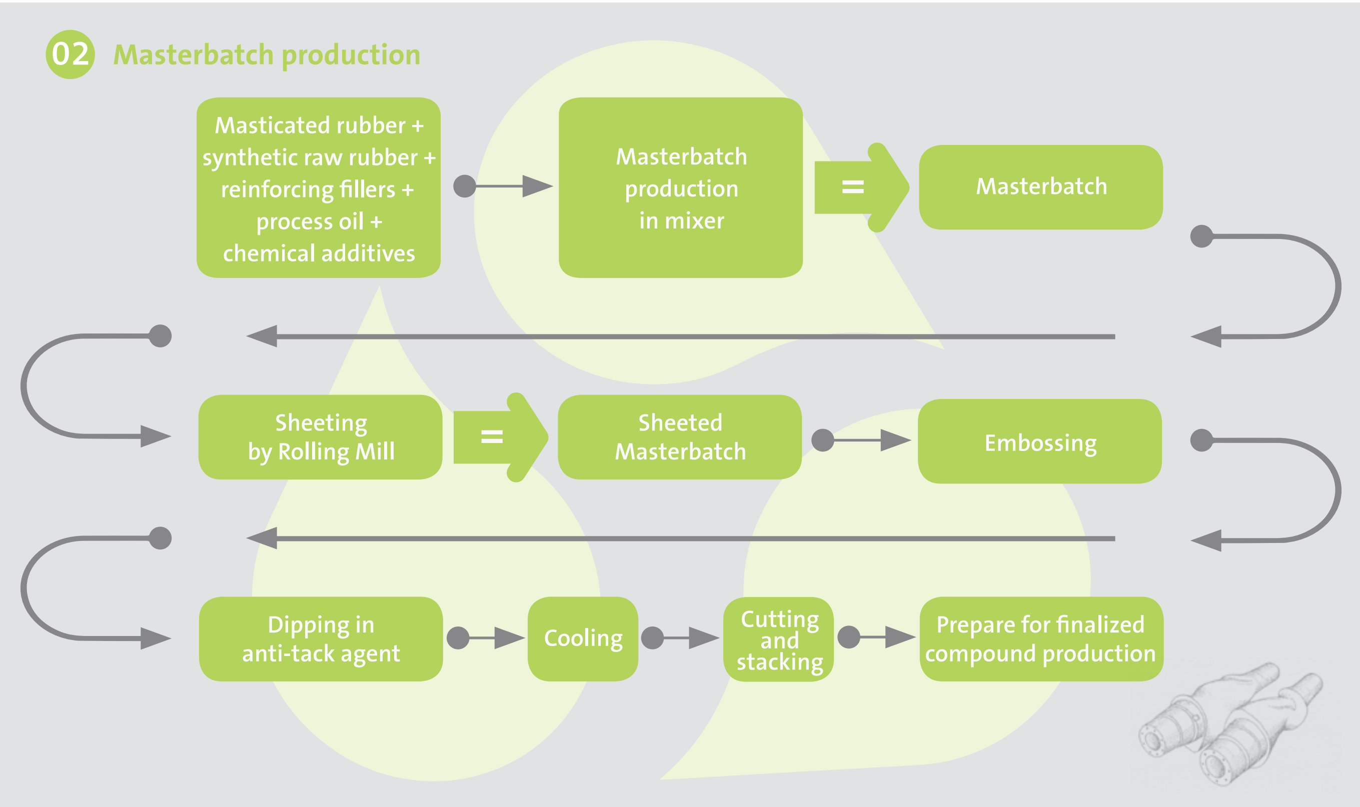


Figure 5: Masterbatch production – Detailed steps

F. Finalization – A Pinch of Sulfur.

In the second step of the mixing process, being the finalization, the masterbatch is mixed with sulfur in preparation for the manufacturing and curing process which will be addressed in the forthcoming part III of the White Paper Series (see figure 6). Sulfur is the most common vulcanizing agent for rubber fenders. It is used in combination with other chemicals that accelerate vulcanization and prevent scorching such as zinc oxide, stearic acid, and others. **While this step is important for effective cross-linking of the rubber's polymer chains (vulcanization), the addition and the thorough mixing of sulfur enhances the final hardness of the rubber and elasticity properties.** After sulfur has been added, an increase in temperature must be avoided in order to prevent premature vulcanization. **The Kneader is the preferred mixing device for finalization because unlike the Banbury, the Kneader does not easily exceed the vulcanization-critical temperature.** The finalized compound is processed on the rolling mill and batch-off machine and is

Finalized compound on rolling mill

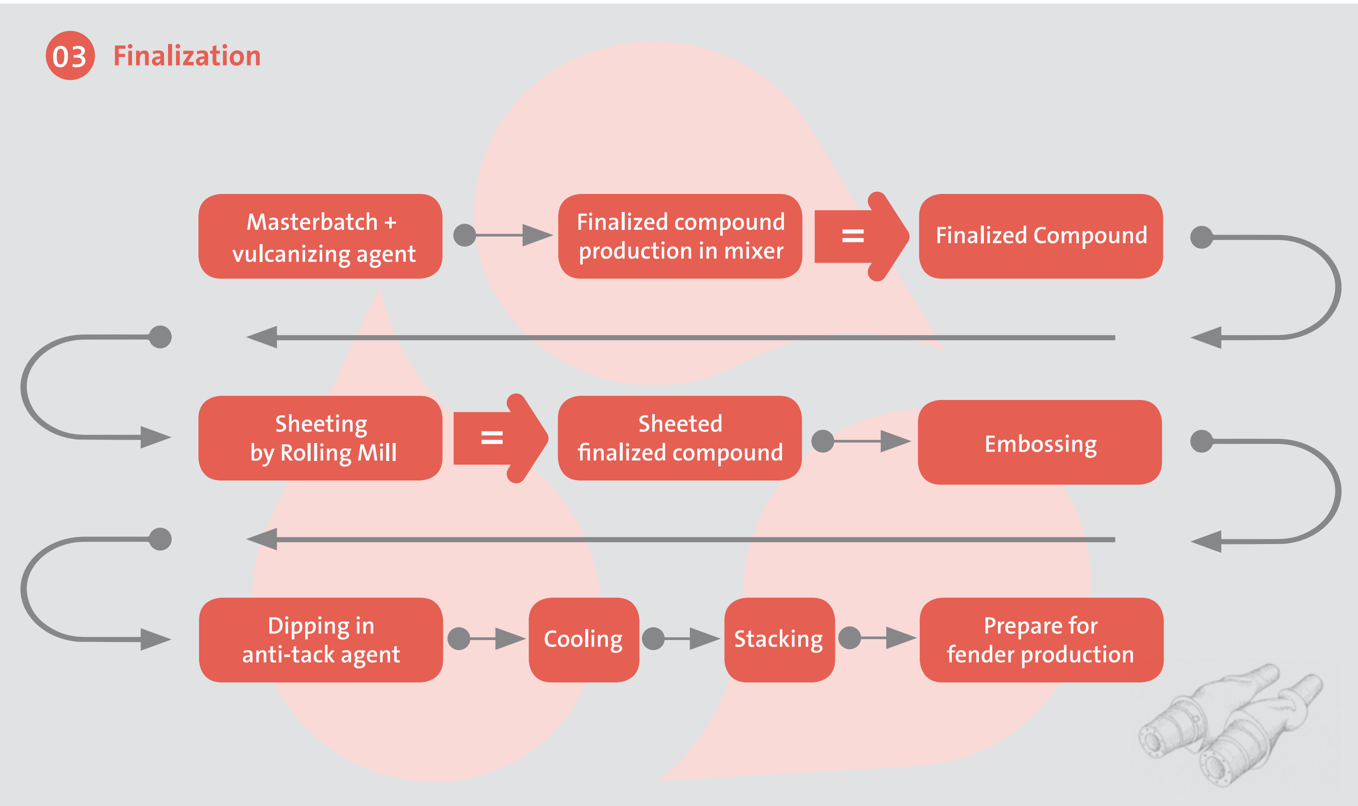


Figure 6: Finalization – Detailed steps

then stored in one folded piece without being cut, which facilitates the further manufacturing process (Part III of the White Paper Series).

The following step of fender production, manufacturing and curing, relies on the exact determination of scorch time, optimum curing time as well as minimum and maximum torque. **These parameters can vary between different compound batches which is why testing and determining these parameters is extremely important regarding the high quality of fender products.** For this purpose, a specimen of the finalized compound is placed onto a Curemeter which determines all relevant data based on a special software in order to schedule the ideal curing parameters individually for each compound. In this way, consistent quality can be reassessed each compound batch.

The same test specimen is used to test the physical properties of the compound. Doing both tests at this stage of the fender production, allows for an early quality assessment.

Test specimen for curementer

Finalized rubber folded for manufacturing process

Conclusion.

From what we have learned so far in Part I and Part II of this White Paper Series, the road from designing the compound for a rubber fender with the desired physical properties to a mixing procedure that adheres to the highest quality standards is a complex one. Rubber compounds for rubber fenders must have superior mechanical strength, flexibility, and durability with a healthy cost-performance ratio. Our mission at SFT is to maximize and harness each material's strength by combining various types of rubbers, fillers, and chemicals with a superior mixing process.

Adjusting the composition for every new fender project according to its requirements is closely followed at SFT, as the characteristics of rubber compositions greatly affect fender performance and durability. Rubber fender compounds can by no means be generalized for the entire industry.

We are not exaggerating when we say that balancing raw materials is a necessity for compound design and an integral part of our experience. **There are infinite combinations of rubber compositions and they all depend on the type and amount of raw rubbers and compounding agents used in the formulation.** We at SFT firmly believe that the expertise in the fields of compound designing, mixing, production and testing are the key to safety, reliability, and durability of a fender.

However, the best formulation of the compound and the highest quality raw materials may not result in a durable rubber fender when inappropriate mixing techniques are involved, or the wrong equipment is used. **Both, the Banbury and the Kneader are reliable and efficient solutions to mixing high-quality compounds and it can even be beneficial to operate both.** The approach to achieving this quality may vary depending on the required physical properties of the final product but has in most cases emerged through a long history of experience with the materials and the processes involved. **Ultimately, the consistency of a multi-layered process such as customized rubber mixing depends to**

a great extent on the operational control over every production step, a solid concept of quality management and once again the manufacturer's experience.

As a fender manufacturer with extensive knowledge and 90+ years of experience in rubber production, we at SFT take on the entire project-specific process from calculations and design to creating and producing a high-quality, durable fender, fully committing to international standards and guidelines, and a clear sense of responsibility.

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Unless indicated otherwise, all references to rubber and rubber mixing in this white paper are quoted from:

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- New Edition, Basic Rubber Technology, Third impression of the revised edition (2010). The Society of Rubber Science and Technology, Japan
- ShibataFenderTeam White Paper #1: Compounding

Note:

- **The physical properties of a rubber fender do not only depend on the quality of the rubber compound. The correct handling of the material in the mixing process and the choice of equipment are equally important.**
- **Selecting the most suitable mixing device for each production step from a range of available devices and profound operator know-how play a vital role in producing a fender that surpasses and complies with international testing standards.**
- **Features of the mixing equipment that are relevant to the final compound quality include rotor speed, temperature development and chamber volume-cooling surface ratio. Large mixers may be efficient, though not necessarily to the advantage of the quality of the compound.**

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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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 2MPa and 15MPa, 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.

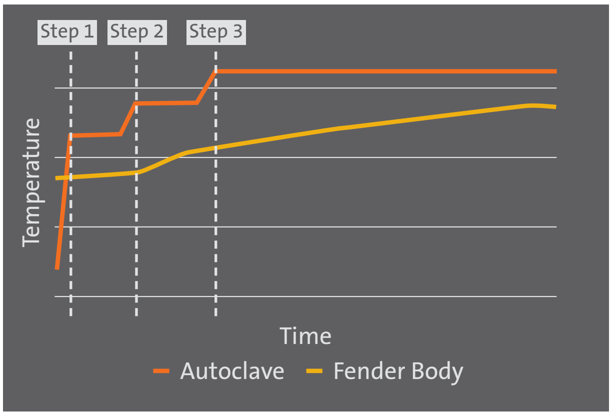


Figure 2: Temperature increase while curing

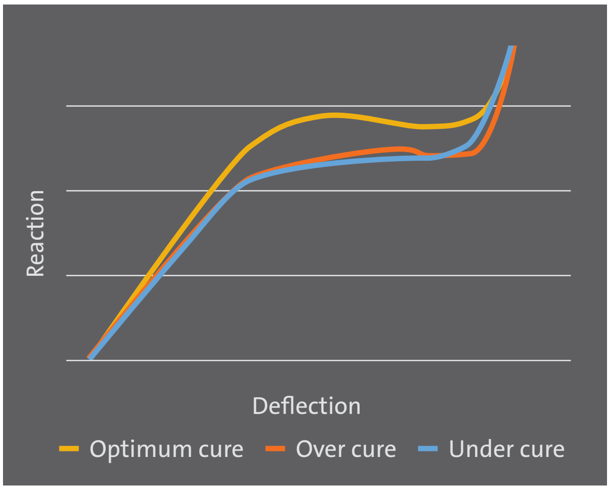


Figure 3: Impact of curing on performance

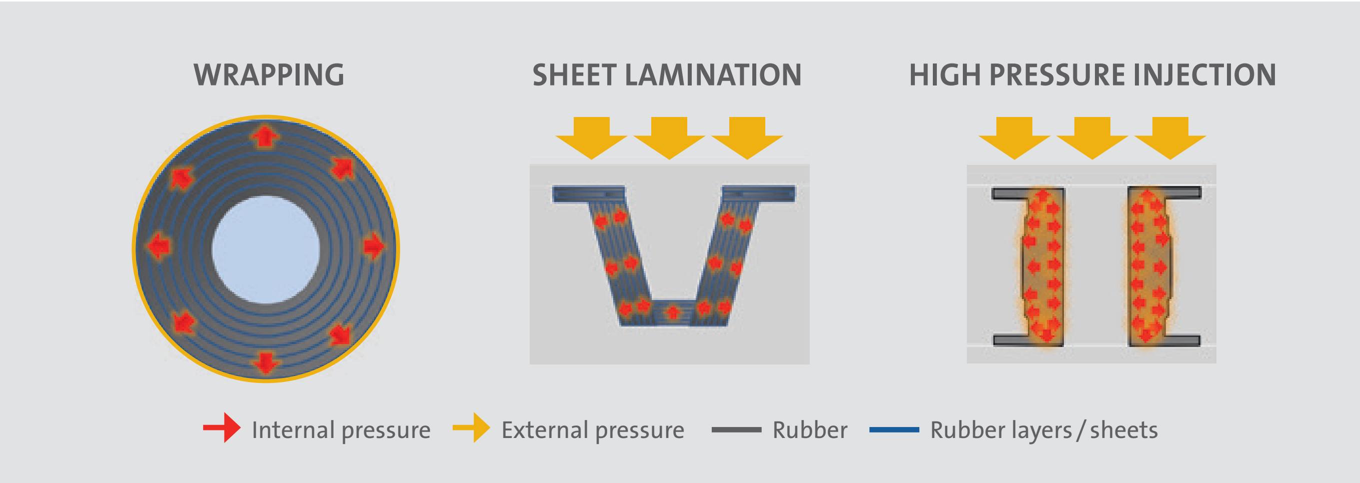


Figure 1: Internal and external pressure while curing

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.

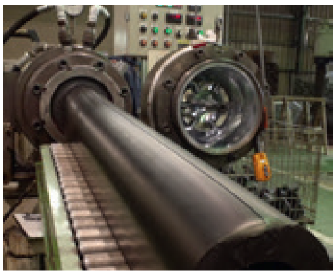
02 Compression Molding / Sheet Lamination Molding

- 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.

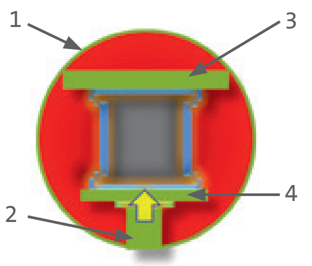
As for manufacturing, curing methods are determined by the fender type and curing parameters must be defined depending on the individual requirements of the fender project. Finding the optimal path that helps the manufacturer to achieve the highest quality is the key of curing and every other step in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

Autoclave

Jacket mold with bolts

CURING METHODS

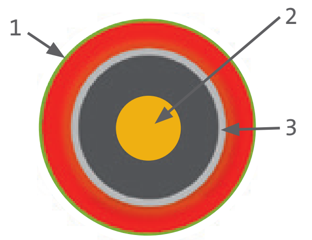
01 Autoclave use for molded fenders



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

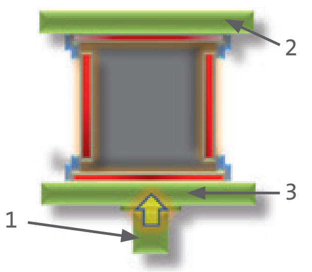


1 Autoclave
2 Pipe Mandrel
3 Nylon strips

** Graphic shows wrapped fender*

- ▶ 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.

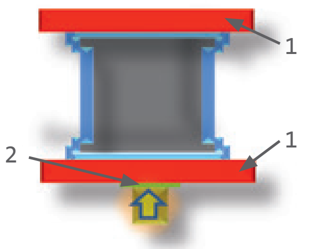
03 Jacket + Press



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.

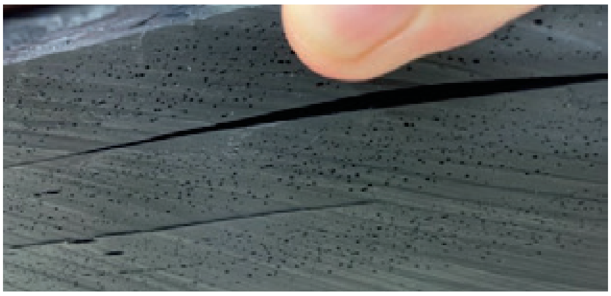
Equipment — Mold — Rubber — Heat

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:

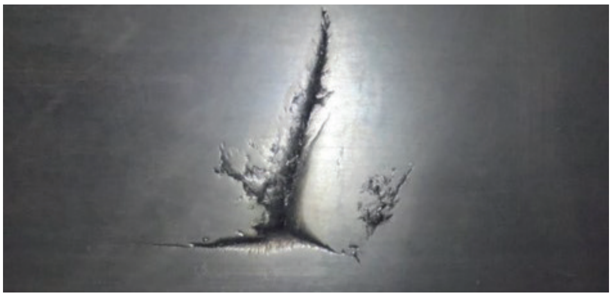
- Voids
- Delamination
- Surface defects such as extensive flow marks
- Insufficient bonding between steel plate and rubber

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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