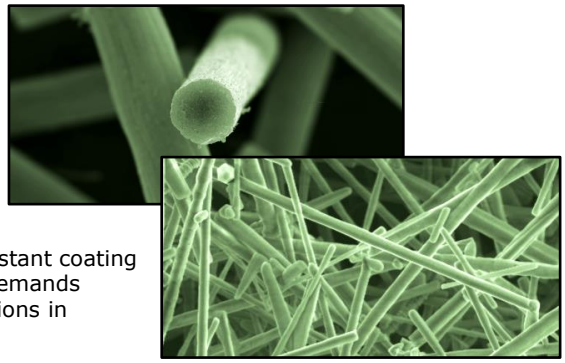
SI-TUFF™
PERFORMANCE SILICON CARBIDE
DELIVERING EXCEPTIONAL PROPERTIES

TECHNICAL DATASHEET



Applications Guide Overview

Congratulations on your decision to develop tougher, more wear resistant coating formulations. While the market for protective coatings increasingly demands increased durability and service lifetime, there have been no innovations in reinforcing additives in over a decade.

SI-TUFF™ Performance Silicon Carbide is a new type of reinforcing additive that is changing the way coatings formulators think about coating reinforcement. It enables levels of performance not before possible, across many different industries and coatings applications. It is safe for food contact applications.

If used properly, SI-TUFF™ is expected to increase service lifetime by 20-50%. Some customers have improved performance by 100%. By reading this applications guide, you are taking the first step in learning how your coatings may benefit from SI-TUFF™. The objectives of this guide are to:

- Explain what SI-TUFF™ Performance Silicon Carbide can do for you, as well as what it cannot do
- Discuss the engineering behind why SI-TUFF™ works
- Review the different product grades of SI-TUFF™ that are available
- Help you avoid common pitfalls
- Provide guidelines to enable successful design

Benefits of SI-TUFF™ Performance Silicon Carbide

The primary benefit of SI-TUFF™ is improved scratch and abrasion resistance, which results in increased service lifetime. Secondary benefits include enhanced thermal conductivity and stability, impact resistance, and hardness. SI-TUFF™ may be used in liquid and powder coatings of all chemistries and application methods.

SI-TUFF™ Performance Silicon Carbide is primarily used when the coatings formulator is challenged with further improving wear resistance without compromising other critical properties. SI-TUFF™ is uniquely valuable for these applications because it improves wear resistance at low loading levels, such that it does not affect other properties including non-stick, friction, and flexibility. For example, it may be used in non-stick cookware and bakeware coatings without affecting release properties, or it may be used in piping coatings without decreasing flexibility and impact resistance.

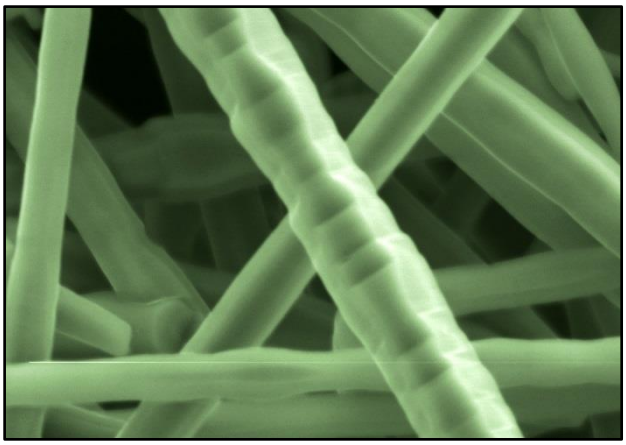
SI-TUFF™ Performance Silicon Carbide will impart a slight gray-green color to the coating; this should be considered for color sensitive applications. Applications that require high clarity may not be a good fit.

SI-TUFF™ may improve thermal properties including conductivity and stability, however it is typically not the best choice if this is the primary performance target; other additive materials are likely to provide better price/performance. Please contact Haydale Technologies Inc. for more information.

Example applications: consumer cookware coatings, industrial bakeware coatings, industrial piping coatings, super durable polyurethane coatings, industrial fluoropolymer coatings, epoxy-Novolac coatings.

How Si-Tuff™ Works: Long Range Force Distribution

SI-TUFF™ is effective because of its unique combination of hardness, mechanical strength and high aspect ratio geometry. It works by forming an interlocking, reinforcing network in the coating. This reinforcement distributes stresses and abrasion forces into multiple, smaller force components over long ranges. The end result is reduced localized coating wear and damage, and a longer service lifetime.



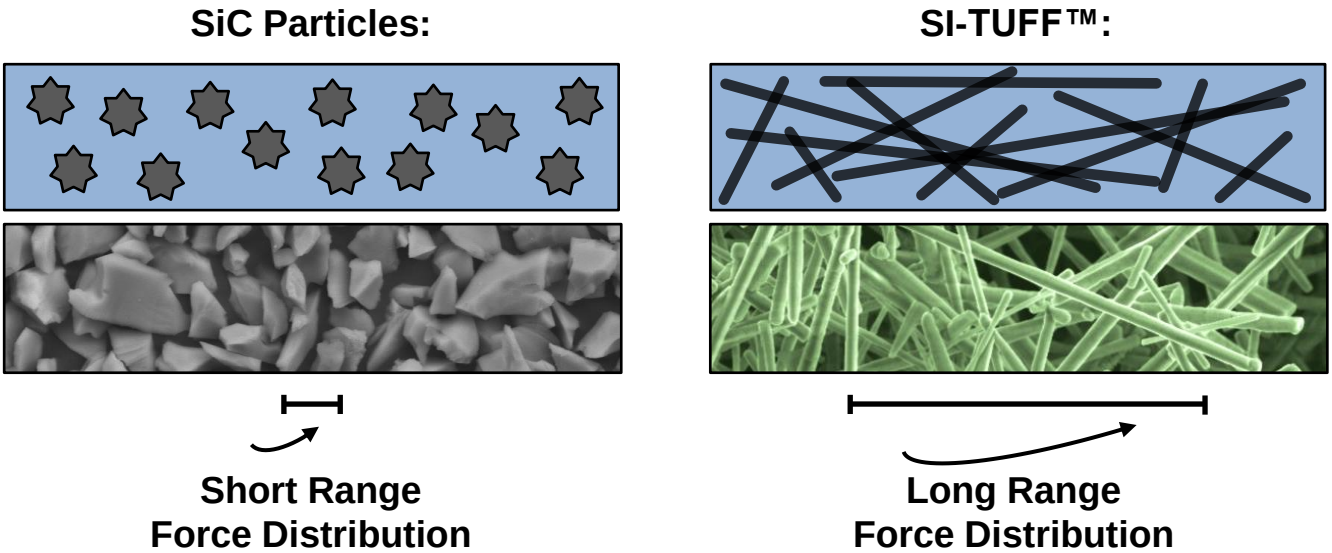
Interlocking Reinforcement

Reinforcing additives are often used to protect softer polymer coating resins with a harder substance. Other mineral additives are often used to reinforce coatings, including SiC particles. These additives are effective at improving wear resistance, however they do not provide long range force distribution.

SI-TUFF™ is often used in combination with other additives to increase the effectiveness of the reinforcement. SI-TUFF™ distributes abrasion and impact forces over longer ranges so that a larger area of the coating is exposed to the same total force; force per area decreases. The hard reinforcement takes the majority of these now-smaller forces, protecting the softer coating resin from damage. When used properly, SI-TUFF™ increases the ability of the reinforcement to do its job.

Increasing additive loading levels typically affects other coating properties, and a trade-off must be made when increasing coating durability. SI-TUFF™ offers higher performance at lower loading levels; it is effective at low loading levels, and it may be used to improve performance without increasing total additive content.

On your first trial, it uncommon to achieve the expected 20-50% performance increase, and often no improvement is observed. Development work is required to optimize performance. A primary objective of this applications guide is to present guidelines which discuss how to effectively approach this development work.



GETTING STARTED: INCORPORATING SI-TUFF™ INTO YOUR COATING SYSTEM

This applications guide is written to help you avoid common pitfalls that result in poor performance, and get your evaluation started on the right track. The following sections provide guidelines for critical design considerations.

1. Product Grades and Availability

SI-TUFF™ Performance Silicon Carbide is available in several different grades for use in protective coatings.

2. Functionalization

Chemical functionalization allows SI-TUFF™ fibers or microfibers to chemically lock into the polymer matrix. This can increase performance in compatible, highly cross-linked coating systems, but can decrease performance in many coatings. Haydale Technologies Inc. recommends beginning evaluation with standard, non-functionalized grades of SI-TUFF™.

3. Existing Coating Reinforcement

SI-TUFF™ can increase performance in any coating system, even if it already contains mineral additives for reinforcement. It may be used in unreinforced coatings without loss of critical coating properties. The design approach is different depending on existing reinforcement.

4. Product Form

Haydale Technologies Inc. supplies SI-TUFF™ as a dry powder, aqueous dispersion, or custom dispersion. For initial evaluation, dispersions prepared by Haydale Technologies Inc. are strongly recommended to ensure uniform dispersion of the SI-TUFF™ fibers and microfibers, and avoid poor performance.

5. Fiber or Microfiber?

Fiber geometry and size impacts performance. Which provides the best results depends on a number of coating properties.

6. Loading Level and Coating Layer

The amount of SI-TUFF™ added to the coating greatly affects performance and economics; more is not always better. In multi-layer coatings, SI-TUFF™ should be added to the appropriate layer.

7. Understanding Loading Level

Loading level can be defined in many different ways. To ensure consistency in communication throughout the development process, Haydale Technologies Inc. clarifies what loading level is important when dealing with SI-TUFF™.

1. Product Grades and Availability

Haydale Technologies Inc. offers several product grades of SI-TUFF™ Performance Silicon Carbide. All product grades are designed for use in protective coatings, and offer different levels of performance depending on your coating formulation.

SI-TUFF™ Performance Silicon Carbide is available in two different geometries: fiber and microfiber. Microfiber grades are single crystal β-SiC with an average diameter of 0.65µm and average length of 10-12µm. Fiber grades are polycrystalline β-SiC with an average diameter of 7µm and average length of 45-50µm. Chemically functionalized grades are not recommended for initial evaluation; see "Functionalization" section for details.

SiC Microfiber:

- P-SW: single-crystal SiC microfiber, 0.65µm diameter, 10-12µm length
- P-SWA: amine functionalized grade of P-SW
- P-SWE: epoxy functionalized grade of P-SW

SiC Fiber:

- P-SF: polycrystalline SiC fiber, 7µm diameter, 45-50µm length
- P-SFA: amine functionalized grade of P-SF
- P-SFE: epoxy functionalized grade of P-SF

Availability

Microfiber grades of SI-TUFF™ Performance Silicon Carbide are produced commercially today and are available immediately for purchase. This includes SI-TUFF™ P-SW, P-SWA, and P-SWE.

Fiber grades SI-TUFF™ Performance Silicon Carbide are in development; evaluation quantities are available today.

2. Functionalization

SI-TUFF™ Performance Silicon Carbide is available in both amine and epoxy functionalized grades. Functionalization allows SI-TUFF™ fibers or microfibers to chemically lock into the polymer matrix. This can increase performance in compatible reactive coating systems, which are typically highly cross-linked systems.

These materials can interact in complex ways with your coating system. In incompatible coating systems, performance can decrease substantially. For this reason, it is recommended to begin evaluation with standard, non-functionalized grades of SI-TUFF™ (P-SW microfiber, P-SF fiber). This limits the number of test variables, reduces evaluation costs, and increases chances for success.

Establishing the benefit first using non-functionalized grades of SI-TUFF™ will set up possibility for further optimization using functionalized grades. All coating systems that are compatible with functionalized grades will also see improved wear resistance using non-functionalized grades.

Amine functionality provides best results in epoxy, Novolac, or other polymer systems that react with amines or use amine crosslinking agents. Epoxy functionality provides best results in urethane or other polymer systems that react with epoxies or use epoxy chemistry in the polymer backbone.

3. Existing Coating Reinforcement

Using SI-TUFF™ Performance Silicon Carbide in an unreinforced coating system often requires a different design approach than a reinforced coating system.

Unreinforced Coating Systems

SI-TUFF™ is unique because it can be used in all layers of a multi-layer coating system, including the topcoat. This is unlike traditional mineral additives, which are not used in some coatings because they compromise other critical coating properties including non-stick, friction, and flexibility. An example is fluoropolymer industrial bakeware coatings; additives are not used in these coatings to preserve the release properties.

In these types of coating systems, SI-TUFF™ may be used by itself at low loading levels to increase wear resistance without compromising other properties. This is a new way of thinking that opens up a range of exciting opportunities that have not previously been possible.

Reinforced Coating Systems

Many coatings already incorporate a heavily optimized reinforcement system. It is easy to think that no further improvement can be made without affecting other properties. Before SI-TUFF™, this mindset may have been true. Customers have demonstrated that no matter how optimized a coating system is, dramatic increases in performance can always be achieved using SI-TUFF™.

SI-TUFF™ may be used in combination with other additives for a synergistic effect, providing stronger reinforcement than either additive by itself. **SI-TUFF™ must be incorporated in such a way that it builds upon and enhances the design of the existing reinforcement**. Development work is required to optimize this design; optimal results are not expected on the first test.

4. Product Form

All grades of SI-TUFF™ Performance Silicon Carbide are available as dry powder, aqueous dispersion, or custom dispersion. **Haydale Technologies Inc. strongly recommends using aqueous dispersion or custom dispersion whenever possible.**

Poor dispersion quality can result in poor performance; it is best to eliminate this potential obstacle when beginning your evaluation. Dispersions are prepared by, Haydale Technologies Inc. and are guaranteed to be uniformly dispersed.

Aqueous Dispersion

They are ready for drop-in mixing, making initial evaluation as simple as possible. Dry powder is not recommended for initial recommendation because of the additional complexity of proper dispersion technique. Additionally, there is a potential respirable fiber hazard that must be considered when working with dry powder.

After establishing successful results in lab and field testing using aqueous or custom dispersions prepared by Haydale Technologies Inc., some customers choose to develop proper technique for working with dry powder on a commercial basis; Haydale Technologies Inc. can help with this process. Many customers continue to purchase dispersions from Haydale Technologies Inc. for the additional ease of handling.

5. Fiber or Microfiber?

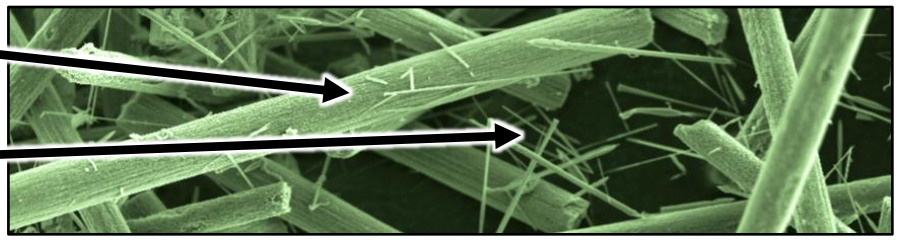
SI-TUFF™ Performance Silicon Carbide is available in fiber and microfiber grades, providing tremendous design flexibility to optimize performance.

SI-TUFF™ Fiber

7µm diameter; 45-50µm length

SI-TUFF™ Microfiber

0.65µm diameter; 10-12µm length

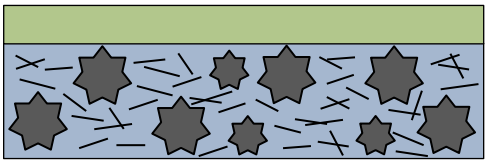


Which size will provide the best performance in your coating system is application specific and requires trial and error to optimize. Because every coating system is different, there is no "one size fits all" solution. However, some general guidelines will help in understanding the performance potential of SI-TUFF™:

- **In selection of SI-TUFF™ fiber or microfiber, it is important to account for the size of other reinforcing additives in your coating system. Particle size matching is usually beneficial.** This helps "connect" the reinforcement together in the most optimal way to form a strong, interlocking network.
- Multi-layer coatings allow for greater flexibility in particle size selection and design.
- In some applications, a combination of SI-TUFF™ fiber and microfiber may be optimal.

The following example illustrates the design flexibility of SI-TUFF™ fiber and microfiber:

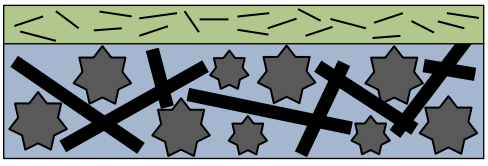
Unoptimized Reinforcement System



SI-TUFF™ microfiber in primer layer with medium and larger size particles. Microfiber length is smaller than the particle diameter, which limits the ability to effectively distribute forces.

Expected result: limited increase in wear resistance

Optimized Reinforcement System



SI-TUFF™ fiber in the same primer layer. Fiber length is similar to particle diameter, allowing SI-TUFF™ to effectively distribute forces over long ranges.

SI-TUFF™ microfiber added to the topcoat creates an additional level of reinforcement, further increasing wear resistance.

Expected result: 20-50% increase in wear resistance

In practice, going from "un-optimized" to "optimized" involves evaluation of several different coating formulations. Every coating system and reinforcement is different, making it hard to predict the results
you will achieve. Haydale Technologies Inc. will help you design and implement a solid experimental plan, and will provide support and guidance along the way.

6. Loading Levels and Coating Layer

Many coating systems, particularly liquid coatings, contain multiple layers. SI-TUFF™ Performance Silicon Carbide is used successfully in commercial coatings today with one, two, and three layers. It is used in primer, mid-coat, and topcoat layers, as well as combinations of more than one layer.

Coating chemistry, application requirements, existing reinforcement, and coating layer all influence the optimal loading level. Coatings formulators are still finding new ways to use SI-TUFF™ in their coating systems to further increase performance. The following are only guidelines:

Topcoat

Incorporating SI-TUFF™ into the topcoat is typically the easiest way to increase wear resistance. Most coating systems do not contain mineral additives in the topcoat; reinforcing this layer with SI-TUFF™ provides an additional level of protection above and beyond any reinforcement contained in the other layers.

It is best to keep loading level below 1.5% to avoid significant loss of gloss and other critical coating properties. Microfiber may be more suitable for the low DFT of most topcoats.

Best results are typically obtained with a SI-TUFF™ loading level between 0.5% and 1.5% in the topcoat.

Mid-coat & Primer Layers

Fiber and microfiber grades of SI-TUFF™ may be used in the mid-coat and primer layers, either by themselves or in combination with particulate mineral additives. Designs in this area are application specific, however best performance is usually achieved when using SI-TUFF™ to *enhance*, rather than replace existing reinforcement. Haydale Technologies Inc. recommends testing both fiber and microfiber grades of SI-TUFF™ Performance Silicon Carbide.

Best results are typically obtained with a SI-TUFF™ loading level between 1.0% and 3.0% in mid-coat and primer layers.

Please refer to the section "Understanding Loading Level" for clarification on how to calculate loading level.

7. Understanding Loading Level

It is no surprise that the loading level of SI-TUFF™ has a tremendous impact on coating performance. Because of this, it is important to clarify specifically what loading level refers to. This ensures consistency in communication throughout the development process.

SI-TUFF™ loading level is calculated on a "solids on solids" basis, in weight percent. Water, solvents, and other volatile components are not included in the calculation.

$$\text{SI-TUFF™ loading level} = \frac{SI\text{–}TUFF™\ Solids}{Total\ Solids}$$

Please consider the following example where a coating topcoat is being reinforced with an aqueous dispersion of SI-TUFF™ Performance Silicon Carbide:

- The coating topcoat solution contains 40% solids.
- Aqueous dispersion of P-SW contains 35% solids.
- What is the loading level of SI-TUFF™ if you add 11.54g of P-SW aqueous dispersion to 1,000g of topcoat solution?

$$\text{Loading Level} = \frac{SI\text{–}TUFF™\ Solids}{Total\ Solids} = \frac{(11.54 * 0.35)}{(1{,}000 * 0.40) + (11.54 * 0.35)} = \frac{4.04}{404.04} = \mathbf{1.0\%}$$

SI-TUFF™ solids

Topcoat solids

Use this formula to calculate how much SI-TUFF™ material should be added to your coating system, based on a target loading level:

$$\text{Grams of SI-TUFF™ aqueous dispersion} = \frac{S_{LL} * C * C_{LL}}{0.35 * (1 - S_{LL})}$$

S_{LL} = target loading level of SI-TUFF™

C = grams of coating solution

C_{LL} = solids content in coating solution

If we use this formula to calculate the amount of SI-TUFF™ aqueous dispersion required to obtain a target loading level of 0.5% using the previous example, we obtain the same result:

$$\text{Grams of SI-TUFF™ aqueous dispersion} = \frac{0.005 * 1{,}000g * 0.40}{0.35 * (1 - 0.005)} = \frac{2g}{0.3483} = \mathbf{5.74g}$$

Contact Haydale Technologies Inc.

We believe consultative sales and technical collaboration is the key to success. For technical and sales assistance, please contact: sales@haydale-technologies.com