



WHITEPAPER

FACT CARBON

FUNCTIONAL ADVANCED COMPOSITE TECHNOLOGY

A WORD ABOUT FACT

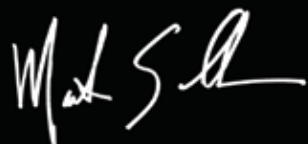
Specialized's vision is to be the best cycling brand in the world. We can only achieve this goal by challenging our own assumptions and constantly re-inventing our bikes and equipment. Thankfully, we have a company filled with dedicated cyclists and demanding pro athletes who never settle for good over great. Case in point: FACT.

FACT (Functional Advanced Composite Technology) is a holistic approach to composite development that differentiates our frames and components from our competitors'. The FACT process—our proprietary blend of design and engineering, materials selection, manufacturing, and testing—allows us to consider the performance of a bike as a whole. We never focus on specific attributes like weight or stiffness without considering the effect on the entire package.

A perfect example of FACT at work is the new S-Works Tarmac SL3. We took nothing for granted in designing this frame from the ground up. We developed new fabrication processes, an innovative carbon layup schedule with internal rib structures specific to each frame size, new BB technology, and new molding techniques that created the smoothest and thinnest layup possible. Through this comprehensive process, we not only improved stiffness and handling, but managed to produce the lightest frame we've ever made and the industry's lightest frameset module.

When it comes to our composites or any other Specialized product, safety is our number one priority. We have one of the world's foremost testing facilities in our Morgan Hill, CA, headquarters with machines that can accurately test around the clock. Our engineers and technicians perform countless hours of testing in all phases of fatigue, ultimate strength, impact strength, stiffness, and vibration, then our pro and elite field testers get their turn. We not only exceed all industry safety standards, but conduct our own proprietary tests, which are far more demanding than the industry requirements.

These days, you could say everybody does carbon—Specialized just does it better.



Mark Schroeder
Director of Engineering
Specialized Bicycles



FACT is an acronym that stands for Functional Advanced Composite Technology, but more importantly, it represents our holistic approach to working with composites. Like any project at Specialized, FACT starts with the needs of the rider, then we apply four critical disciplines to achieve the design targets that will best serve those rider needs: design & engineering, material selection, fabrication process, and testing. What's the result of the FACT process? Bikes and equipment that promise real-world performance benefits for the target rider.

FACT BIKES ARE IN IT TO WIN

EPIC - REVIEWS

"The headline is that the 2010 Epic is a better bike than we've ever seen."
- What Mountain Bike Magazine

"No pedal stroke is wasted on the climbs and no extra energy is needed to control the bike on descents thanks to an incredibly stiff front triangle, nearly perfect suspension and flawless handling."
- Bicycling Magazine

WINS

2009 U23 World Championship
2009 XTerra Cup Series
2009 Sea Otter XC
2009 Pro XCT Team Classification
2008 XC World Championship
Bicycling Magazine Editor's Choice Award, Best Performance XC Mountain Bike
Bike Magazine Germany's Most Innovative Bike Award
2009 International Constructors Award

**ERA - REVIEWS**

"The Era is easily the sweetest freakin' bike I've ever ridden. I've been doing some epic days on it, and it's just killer. Love, love, love it."
- Selene Yeagar, contributor to Bicycling Magazine

"The Era is a capable descender that truly shines on the climbs ... If you're a female racer searching for a bike specially built to meet your competition needs, the Era is the bike you've been waiting for."
- Mountain Bike Action

WINS

2009 XC World Cup #6; Bromont, Canada
3x Winner 24-Hour Solo World Championship

**STUMPJUMPER - REVIEWS**

"The most technologically advanced cross-country hardtail race bike that we have ever had the pleasure of throwing a leg over."

"This bike doesn't accelerate as much as it explodes."
- Both from mbaction.com

WINS

2009 Sea Otter Short Track
Women's 2009 Leadville Trail 100

**TARMAC SL3 - REVIEWS**

"This bike makes no apologies and doesn't need to-it's that good."
- Philip Booth, Road Bike Action Magazine

WINS

2009 Liege-Bastogne-Liege
Multiple 2009 National Championships Winner
Stage win and 2nd place overall, 2009 Tour de France

**ROUBAIX - REVIEWS**

"Not only did this carbon bike receive higher marks for climbing and handling than most of the race bikes we tested, it also dominated the comfort category. Don't be fooled by the word comfort, though. This is an elite racer ... already proven in europe's grueling cobbled classics."
- Marc Peruzzi & John Bradley, Outside Magazine

WINS

2x Winner Paris-Roubaix
2008 Paris-Roubaix
2009 Paris-Roubaix

**SHIV - REVIEWS**

"If I could only use one word to describe the Shiv, it would have to be 'fearsome'. The Shiv looked like it was irritated to be standing there stationary, displayed on a table."
- Neil Browne, Road Magazine

"Riding the Shiv, I consistently had the feeling that the bike's limits were beyond my physical abilities. The bike is designed for the fastest time trialist in the world and it shows. In the hands of Cancellara, the Shiv will cut a straight line to the top of the podium."
- Philip Booth, Road Bike Action Magazine

WINS

2009 TT World Championships
2009 Danish National TT Championships
Prologue and final time trial, 2009 Tour de Suisse
Stage win, 2009 Tour de France
Prologue and stage win, 2009 Vuelta a Espana
Stage win, 2009 Tour du Poitou
Stage win, 2009 Eneco Tour



FACT DEVELOPMENT PROCESS

FROM EXPERIENCE PHILOSOPHY TO FINISHED PRODUCT

It's a universal truth. Different types of riding demand different qualities from a frame or component. That's why, from day one, we design for those differences. We call them "experiences".

Before development even starts, our design and engineering teams set out to fulfill a specific rider experience with each bike. Guided by the needs of that experience (e.g. XC race, Endurance Road, etc.), they determine the best combination of properties—including stiffness, compliance, strength, and weight—for each product.

With the experience as a foundation, the development of every FACT bike or piece of equipment moves through an integrated process where design, materials, and manufacturing are all chosen in careful consideration of one another. This integration of development ensures that each product is 100% built for its intended application—to give the rider exactly what they're looking for, every ride.

DEVELOPMENT PROCESS

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FABRICATION PROCESS	PAGES 15-17
TESTING/REVISION IN LAB & FIELD	PAGES 18-23

OUR PROS HELP POWER OUR INNOVATION

Sure, there's an obvious draw to sponsoring two Pro Tour teams (not to mention our individual athletes and grassroots teams)—the race wins, the brand presence, the "cool factor" of being associated with riders who can pedal over 250km a day. But the real luxury in sponsoring teams like Saxo Bank is that they know exactly what they need and want, and they aren't afraid to ask for it. By giving us feedback and suggestions on our bikes and equipment, they help us develop better products and drive innovation.

For our newest time trial machine, the Shiv (winner of the 2009 TT World Championships), we worked with Saxo Bank every step of the way to help develop the geometry, frame shape, and layup and to validate our prototype frames. Fabian Cancellara, the Schleck brothers, and Team Director Bjarne Riis were particularly integral to the process, giving us priceless feedback we couldn't get anywhere else. From the start, Riis set definitive performance targets for the Shiv. He had ridden our Transition—previously our only triathlon/time trial bike—and came back with a laundry list of suggestions for the new frame.



TUBE SHAPE BY DESIGN



Frame prepared for strain-guage testing



We design and optimize each tube size for each frame size. Here we show down tube sizes.

Beyond just aesthetics, the shape of a carbon frame or component has a huge impact on how it will perform. Smart tube shapes don't just happen; they are the result of months of R&D, field testing, and years of experience riding previous models, including those of competitors.

Here are the factors we consider when optimizing tube shapes:

STRAIN GAUGING – Allows us to determine the ratio of bending vs. stiffness in each tube and to compare the relative importance of those tubes in different stiffness scenarios.

FEA STUDIES – Through this computer modeling software, we can isolate different tubes for pure bending or torsion stiffness load cases or a combination of both. Full frame studies show the effect of triangulation in the front and rear triangles and the effect of a bowed top tube on compliance.

EXPERIENCE – Simple. We watch how tubes deform in dynamic and static fatigue tests and make modifications based on our findings.

TUBE LOCATION – Our tube shapes are designed to resist specific forces, depending on their location. We shape the top tube differently than the down tube, for example, because each tube sees more or less loading, plus a different ratio of bending and torsion stress, depending on the riding scenario (e.g. sprinting, descending, etc.).

FRAME SIZE – The way we see it, different frame sizes warrant different tube sizes. If we didn't design each tube in this manner, a larger frame would have inherently lower stiffness due to the length of its tubes (meaning they flex more than a short tube under the same load). And at the same time, larger riders are capable of applying more force on their bikes. This makes determining the appropriate level of stiffness for each size bike/rider extremely important.

By designing the top tube, down tube, seat tube, and seatstays for each frame size, we can accurately and efficiently control stiffness variables from our smallest to largest frame sizes. Though size-specific tubes require much more work from the engineers who have to painstakingly design each tubeset, the result is a proportional range of bikes with consistent ride qualities across every platform (e.g. Tarmac, Roubaix, Amira, etc.).

CARBON-CENTRIC DESIGN

We approach the engineering of our tube shapes and joints through a concept we like to call carbon-centric design. Carbon can be molded into just about any shape with proper engineering, but by designing tube shapes with the properties of the material in mind, we can create a much more optimized structure.

On its own, carbon fiber only possesses tensile strength. But when a flat sheet of prepreg (resin-impregnated carbon) is cured, it gains some compression strength and some bending strength. So by properly layering these prepreg sheets during the bike's layup process and utilizing the carbon in an efficient geometric shape, we can create tubes that are capable of resisting tensile, torsion, and compressive forces, all of which we encounter while riding.

The real science lies in the ply angles of the carbon. Zero-degree carbon plies work to resist bending and +/- 45 degree angle plies resist torsion. When twisted, either the + or - 45 degree fibers are in tension (depending on the twisting direction), but when bending, one side of the tube is in tension and the other in compression. Long story short, by putting as many fibers as possible in tension (carbon is at its best when it's in tension), we can create a stronger, stiffer bike. This is why it's fundamental for us to know the ratio between bending and torsion in each tube.

Beyond the properties of the material itself, here are the other considerations we make in carbon-centric design:

Carbon fibers aren't as strong when bent at extreme angles, so our engineers focus on eliminating sharp corners, creating smooth transitions, and utilizing large radii tubes.

To maximize structural properties such as strength and stiffness, our engineers use frame and tube geometry to their greatest advantage—an example being the Tarmac SL3's large down tube and bottom bracket junction, which helps the bike achieve a superior stiffness-to-weight ratio.

We eliminate the need for extra carbon material (which other manufacturers might use to build in a margin for error to account for less-than-precise manufacturing) by making our tooling, layup, and molding processes as efficient as possible. Our hard work early on in the design process is what allows us to make frames and components of such consistent quality.

FACT FORKS GO CARBON-CENTRIC



A carbon road fork undergoing ultimate strength testing



A cut-away of our tapered crown design. U.S. patents 7,520,520 and 7,537,231

Carbon-centric design doesn't stop at frames; every component we create, including our FACT carbon forks, follows the same design philosophy.

Traditional fork designs use a large flat crown surface as a seat for a standard crown race—a design borrowed directly from alloy and steel forks. However, since this shape demands 90-degree changes in geometry, it diminishes the effectiveness of the carbon fibers (considering, as we said before, that carbon is strongest in tension).

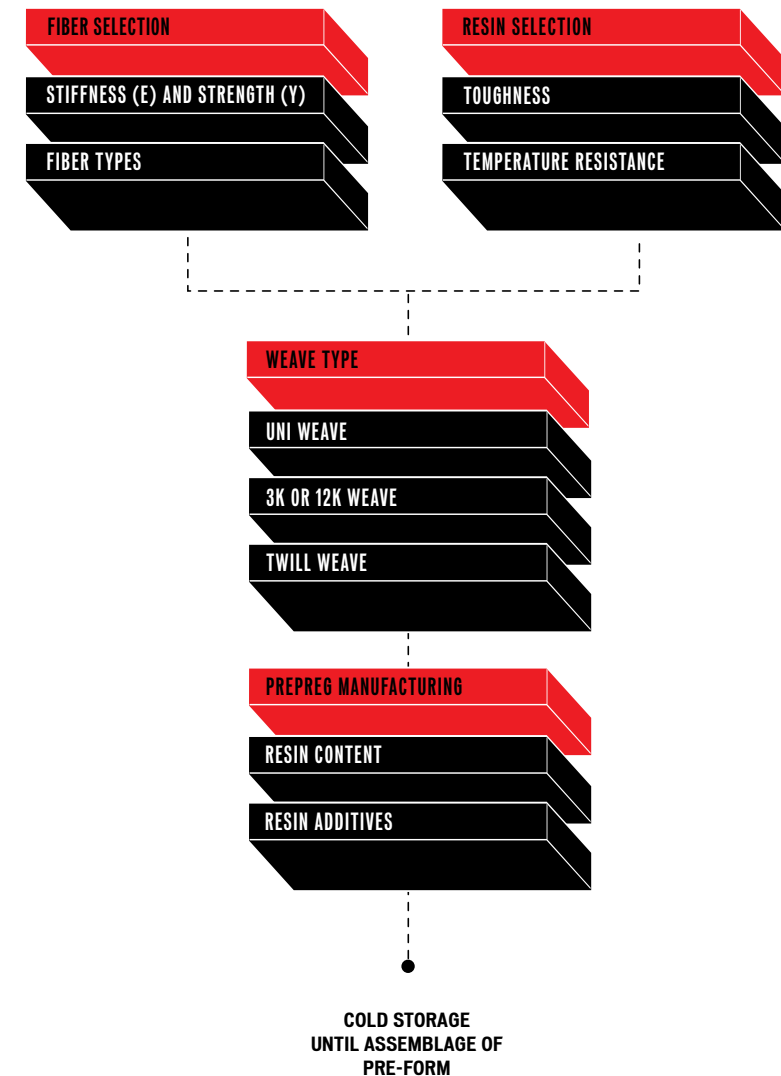
In 2007, we introduced our first tapered crown/raised bearing design and put it on our Roubaix bike. The tapered section of the crown accommodates the bearing and allows the carbon fibers to flow smoothly between blade, crown, and steerer. By virtue of its geometry, tapering also provides a stiffness/strength advantage that we can prove through FEA studies. Finding this design to be widely successful, we've since applied it to all of our FACT full carbon forks, and now, we even use raised bearings on the majority of our carbon mountain bikes.

Fork strength and stiffness are, without question, two of the most important attributes of the bike and something we really focus on during development and testing. Strength aside, stiffness is what makes your front wheel track well when cornering and descending, so it's paramount to the quality of your ride.

By increasing both lateral fork stiffness and steerer tube torsion stiffness, our tapered crown design creates a more confident handling bike.

MATERIALS SELECTION

THE PROCESS BY WHICH WE SELECT MATERIALS FOR OUR FACT BIKES AND EQUIPMENT

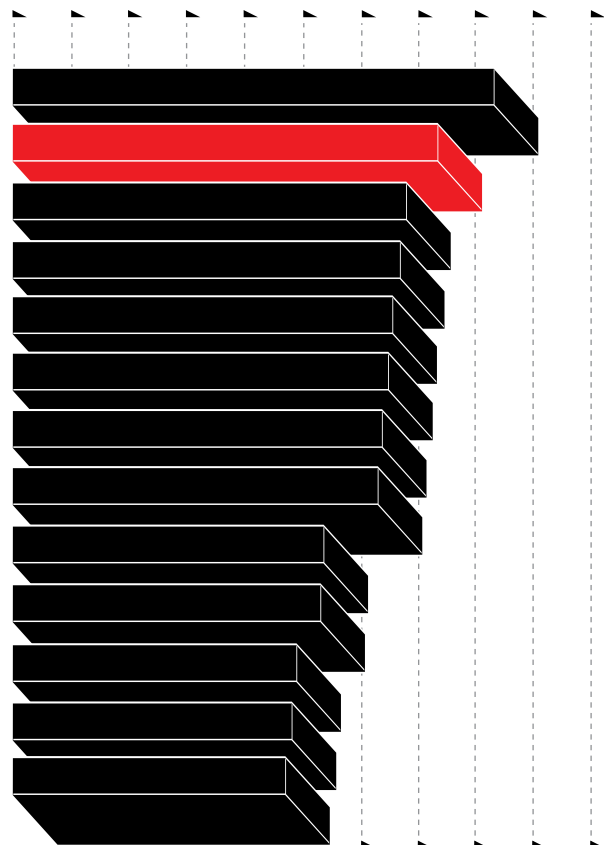




STIFFNESS-TO-WEIGHT BB TESTING

Just like torsional stiffness-to-weight, a higher number indicates greater stiffness. Generally, the stiffer the structure is to the rider's pedaling forces, the faster the frame will respond to rider acceleration. With the SL3, we shot for a high stiffness number, then focused on maximizing torsional and rear triangle stiffness, while reducing weight.

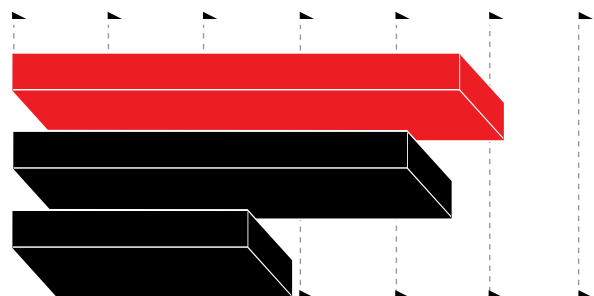
For this test, each frame is fixed at the head tube and rear dropouts and angled slightly to simulate the side-to-side motion of a bike during heavy sprinting loads. Weights are applied at the pedal through a simulated crank arm and chain at the power-stroke position, then the deflection at the BB is measured and the results are divided by frame weight.



VERTICAL COMPLIANCE TESTING

This test measures how a frame responds to loads applied in a vertical plane, which correlates to ride comfort. As a frame gets more compliant, it becomes less stiff. A higher number represents more compliance. This is an isolated vertical compliance test, independent of torsional or BB stiffness.

Each frame is positioned vertically—allowing it to roll at the front and rotate at the rear dropouts—and a vertical force is applied at the saddle. The distance between the BB center and the top of the seatpost is kept constant on all frames. The deflection measures the ability of the frame and seatpost combination to absorb shock in a vertical plane.



MODULE BB STIFFNESS TESTING

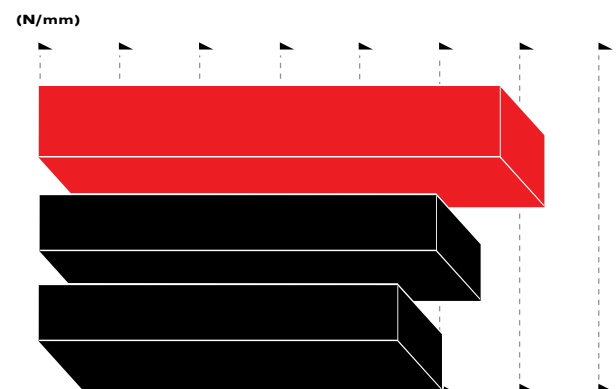
A BATTLE OF THE BOTTOM BRACKETS: WIDE BB VS. SPECIALIZED OSBB

Some of our competitors have made slanted claims about the superiority of wide bottom brackets, and we wanted to set the record straight: Using an ultra-wide 90mm BB, in contrast to a proprietary system like our 68mm OSBB or even the standard BB30, doesn't in itself make for a stiffer frame.

It's important to note that both 90mm and 68mm bottom brackets allow for a larger diameter down tube and seat tube, which will inevitably increase stiffness. But since our OSBB system is designed in tandem with our FACT carbon crankset, we can achieve even greater module BB stiffness than the 90mm designs, while still remaining BB30-compatible.

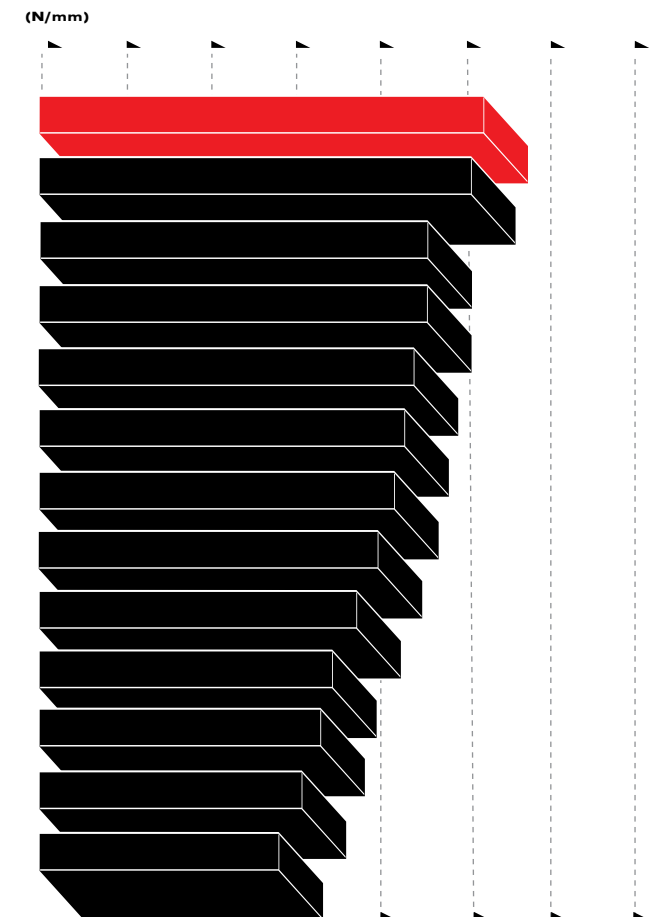
To illustrate this concept, we created a new test called "Module BB Stiffness" (see pg. 18 for picture of test). It's set up just like a standard BB stiffness test, but the frame is paired with the real crankset to better measure the BB stiffness of the overall system. As you can see, we clearly out-perform the other guys.

Note: The competition's modules are tested with a Dura Ace 7900 crankset.



REAR TRIANGLE STIFFNESS TESTING

Sometimes stiffness and weight measurements are too general. So we conduct several proprietary tests on select parts of the frame to help us analyze variables that might otherwise get overshadowed. We won't reveal too many details into this process, but one such test is rear triangle stiffness.





THE BIKE AS A RIDE-ABLE TRANSDUCER

MOVING BEYOND STATIC TESTS AND COMPUTER SIMULATIONS

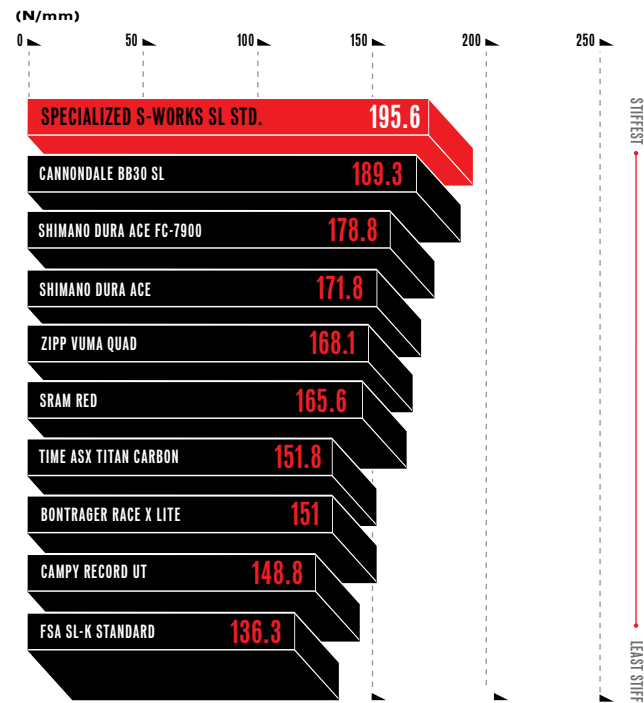
We've made rapid advances in the last several years in terms of the performance and ride quality of our carbon frames. It's not just our commitment to testing (read Mark Schroeder's introduction on pg. 2 if you have any doubts) that pushes us forward, but our constant drive to get inside the bike (metaphorically speaking, of course) and determine exactly what's happening in each tube under real riding and racing conditions.

Stiffness tests are a great benchmark for frame development, and finite element analysis allows rapid prototyping, but the act of riding is so dynamic that it can't be fully duplicated with a static test or computer simulation. Naturally, we saw these limits as opportunity. After a long, arduous process, we found a way to turn the bike frame into a ride-able transducer, capable of gathering bending and torsion data along each tube.

The transducer frame was ridden in every possible manner—sprinting, climbing, descending, pedaling while turning, etc. From the tests, we gathered mountains of data that illustrated the relationship of bending vs. torsion in each tube and how each tube relates to the other. We mapped the load paths through the entire bike frame in every riding situation.

The numbers we pulled from the transducer frame allowed us to optimize the shapes of our bikes to resist the specific loads they would encounter in the field. Take a good look at a bike like the Tarmac SL3—think about how each tube is designed with variable diameter, shifting from circular shapes to flatter, more rectangular ones, yet all blending together—these subtle changes are no accident.

CRANK SYSTEM STIFFNESS DATA



Note: See pg. 23 for photo of crank stiffness test.



S-WORKS SL FACT CARBON CRANKSET

THE STIFFEST, LIGHTEST SYSTEM AVAILABLE. NO JOKE.

Our 2nd generation S-Works SL FACT Carbon Crankset is one of the best examples of the merits of systems integration. This proprietary crank is designed together with our oversized bottom bracket shell (also BB30 compatible) to deliver superior stiffness, strength, and balanced performance at only 597 grams—that's lighter than even the biggest names in components.

KEY FEATURES

- Lightest and stiffest crankset on market; see charts
- FACT carbon removable spider
- Self-adjusting 42mm ceramic cartridge bearings
- Smooth-shifting S-Works SL aluminum chainrings
- BB30 compatible

INTEGRATED CARBON-CENTRIC DESIGN

Creates best weight and stiffness with better fatigue life.

The S-Works SL FACT Carbon Crankset uses a patented integrated construction that's functionally different from traditional configurations. Typical carbon cranks cut fibers at the BB axle/arm interface, which creates a potential weak spot in a very high-stress area. But the SL's integrated crank design allows the carbon fiber to transition seamlessly into the bottom bracket with only one connection point at the center of the BB shell—eliminating the typically independent BB axle.

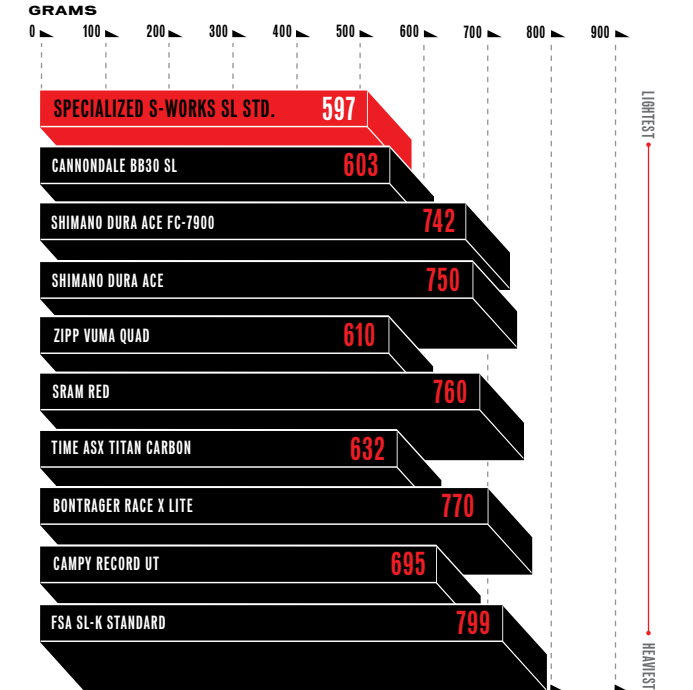
Since this design optimizes the layup of carbon fiber within the bottom bracket, we can engineer the SL crank with completely hollow crank arms for greater stiffness and lighter weight and even add material at the center connection for more strength (without a weight penalty). Finally, replacing the typical steel bearings with new ceramic bearings adds durability and offers less rolling resistance.

REMOVABLE CARBON SPIDER

Balances stiffness and gives the rider more options.

Most crank spiders are integrated into the right crank arm and create big discrepancies in crank arm stiffness from left to right—a fact that's often hidden by overall weights and measurements that don't take side-to-side balance into account. The SL's removable carbon spider balances stiffness from left to right, adding to the efficiency of your pedal stroke. At the same time, it gives riders interchangeability between different spider and chain ring sizes and also enables the use of SRM and Quarq power meters. The S-Works SL crank is found exclusively on the S-Works Tarmac SL3, but is also available aftermarket.

CRANK SYSTEM WEIGHT DATA





SPECIALIZED BICYCLE COMPONENTS, INC.