TUBING SHAPES UP

Bicycle tubing has been 'round for a long time. But these days, bicycles with round tubes are the exception to the rule. Are shaped tubes simply a matter of fashion, or do they make good engineering sense?

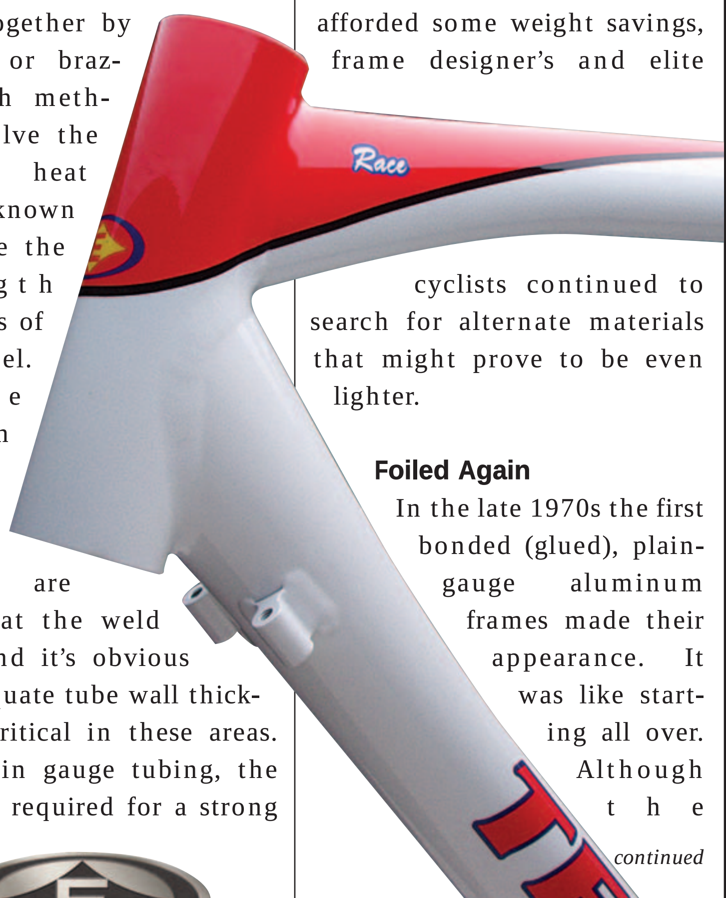
In this month's R&D Technology Report we'll take a look at the evolution of bicycle tubing. We'll focus on the shape and wall profiles of frame tubing and attempt to understand what they do and how they work.

America saw its first safety bicycle in the late 1800s. The frame design was based on a "diamond shape." This frame, which was really two triangles joined together, has been the standard of frame design for well over a hundred years. While the development of new-age materials has prompted some bicycle designers to explore other possibilities, it is hard to beat the efficiency and weight savings enjoyed from a double-triangle frame.

Of course frames made in the 1800s were heavier than frames made today, but that doesn't mean they were necessarily slower. The record for a 100 mile ride in 1885 was a very respectable, 7 hours, 6 minutes and 6 seconds!

In the 1800s all bicycle frames were made using high-carbon steel with a uniform wall profile. Today, we refer to this as *plain gauge tubing*. Steel was the material of choice because of its high strength, ease of fabrication, reliability and safety. More advanced Chrome-molybdenum (cro-moly) steel tubing didn't come around until decades later.

Steel frames are joined together by welding or brazing. Both methods involve the use of heat which is known to reduce the strength properties of the steel. Couple this with the fact that frame stresses are greatest at the weld joints, and it's obvious that adequate tube wall thickness is critical in these areas. With plain gauge tubing, the thickness required for a strong weld joint makes for a relatively heavy tube.



Joined at the Butt

The next step in the evolution of frame design was aimed at weight reduction. Butted tubing was developed to take advantage of the fact that the stresses that act on the middle of the tube are less than those on the ends. As a result, the wall thickness of the tubing in the middle can be reduced without compromising safety. In cromoly steel tubing the difference between the thick wall and thin wall is relatively small — as little as one 100th of an inch. While butted steel frames afforded some weight savings, frame designer's and elite cyclists continued to search for alternate materials that might prove to be even lighter.

Foiled Again

In the late 1970s the first bonded (glued), plain-gauge aluminum frames made their appearance. It was like starting all over. Although the

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strength and stiffness of aluminum is much less than that of steel, the diameters of the early aluminum tubes were modeled after traditional steel tubes. Big mistake! In their quest for weight reduction, bicycle frame designers forgot to consider the lower properties of the aluminum in terms of strength, stiffness and fatigue life. Because of this poor design judgement, aluminum frames all but disappeared from the market.

If you are a long time reader of these Technology Reports, you know the importance of considering material properties in the design process. You cannot switch materials without re-evaluating and updating the design.

How TaperWall™ Works

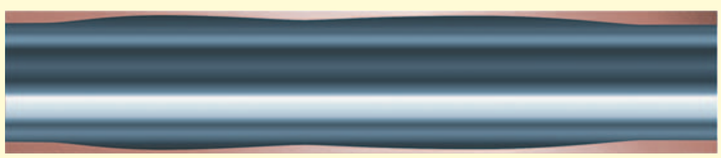
Tubes with thicker walls on the ends and thinner walls in the middle offer advantages over plain-gauge tubes. You only have to look at nature to understand why.

Look at a tree. Look at where the tree limb joins to the trunk. Notice how the joint at the trunk is thicker, larger in diameter than the end of the branch. This is natures butting. Pull on the end of the branch and the limb will flex and curve uniformly towards the ground. This is an example of the limb spreading the stress over the length of the branch, allowing the stress to dissipate over a larger area. This allows the branch to withstand greater stress than it could if the branch did not bend and arc.

Frames can work like this too if the right combination of geometry is present.

TaperWall aluminum tubes with walls that are thicker at the end and much thinner in the center act similar to the tree branch by allowing stresses to transition away from the junction where the tubes join together.

When a frame is welded together the tubes begin to support each other. If the tubing walls are thicker in the high stress area, the joints, and the walls are thinner in the middle of the tubes, the tubes will be most compliant in the middle. This allows for a better "feel" when riding — the ability to absorb more impact stress and gain greater fatigue life. All that and you can't even see it because, unlike the tree branch, TaperWall technology takes place on the inside of the tube.



Cross section of an Easton TaperWall tube shows multiple tapers with dramatic variations in wall thickness.

Aluminum: the Sequel

In the early 1980s, a graduate student named Gary Klein researched an interesting subject for his graduate project. He developed a different approach to making an aluminum bicycle frame. Gary chose oversized, large-diameter, thin-walled tubing and welded it together. The increased diameter solved the problem of a flexible-frame, and welding the tubes together proved to be more reliable than bonding. The tubes were plain gauge. The large diameters compensated for the lower strength of the aluminum. The only complaint had to do with the stiffness of the frame. Some riders felt that the large diameter tubes made the frames too stiff and the ride a bit harsh. But everyone loved the weight savings.

So what to do? The lower strength of the aluminum dictates the use of large diameter tubes. Large diameter tubes lead to harsher riding frames.

The Next Logical Step

Chuck Teixeira, an engineer at Easton Aluminum (as the company was known at the time), accepted the challenge. Chuck's idea was to develop mid-diameter aluminum tubes with varying wall thickness. If successful,

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the advantages would include further weight savings and better ride compliance than larger diameter tubes.

It was the strength issue Chuck had to overcome. Chuck solved the strength issue by developing a manufacturing process to change the wall profile of aluminum tubes.

The Rest is History

The now renowned Easton TaperWall™ process allows material to be thicker at the ends of the tube and thinner in the center of the tube, much like butted steel tubes. Unlike the butting process however, TaperWall allows for much larger variations in wall thickness between thick and thin. A TaperWall tube profile could change as much 1.4 mm from thick section to thin section. Furthermore, the process allows for multiple areas of wall thickness variation in a single tube. Never before had anyone been able to control a tube's wall profile to this degree. Easton's technology revitalized the use of aluminum as a viable and important material for bicycle tubing.

Getting in Shape

In the last few years, bicycle frames have taken on a new look. Tubing that features shapes like oval, rectangle, tear drop, aero and pear tubes have become popular in frame design. Manufactures continue to look for ways to differentiate their bicycles from one another.

Do these shapes perform a function beyond looking cool? The answer is sometimes yes and sometimes no. It is hard to beat the shape of a round tube. A round tube maintains consistent characteristics 360 degrees around the tube. No matter which direction you apply a load, a round tube's strength and stiffness properties remain the same.

> ***"It is hard to beat the shape of a round tube. A round tube maintains consistent characteristics 360 degrees around the tube."***

Compare that to an oval tube. An oval tube will gain stiffness in one direction while losing stiffness in another. There are many applications in frame design where this could be useful.

Very Varying Tubes

In simple terms, tubes used in frame making today can be classified into two categories.

Level-one tubes are butted or TaperWall tubes with a level outer diameter. It is possible to press a level-one tube into a shape.

Level-two tubes are TaperWall or butted tubes that are not only shaped but feature changing cross-sections along the length of the tube.

Level-two tubes are the most

Level-two tubes manufactured by Easton feature changing cross-section shape as well as diameter (cross sections of tube ends are shown).

complicated to manufacture. They are first designed using advanced computer modeling to determine the shape. Stress analysis is applied to verify that the design will dissipate the stress in the most effective manner. Often the next step is to make a model of the tube using wood or resin to ensure the shape is pleasing to the eye.

If everything checks out, the processes to manufacture the tubes are then identified. Level-two tubes often combine many different processes. Initially,

> ***"Level-two tubes provide the best of all worlds. Not only does the outside shape change but the wall cross sections can change as well."***

Easton draws blank tubes on their computer-controlled draw benches. This increases the tubes properties through grain refinement and cold working. The tube's diameter is then manipulated through swaging or sinking (processes that change the outside diameter). Lastly, the tube might be drawn or pressed into its final shape.

Level-two tubes provide the best of all worlds. Not only does the outside shape change but the wall cross sections can change as well. For example, a level-two tube might start out square on one end and gradually change to a larger oval shape on the other end. The possibilities are endless.

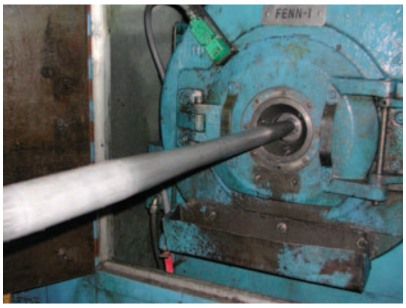
Although it's tempting to let fashion dictate the shape of tubes used in a frame, care must be taken to insure that strength and ride quality are not compromised. Remember that, unlike round tubes, shaped tubes do not offer consistent strength characteristics in all directions. To take full advantage of shaped tubing technology, frame design and engineering is critical.

A designer can now engineer tubes that enhance joint strength and, at the same time, build in compliancy and/or stiffness where desired.

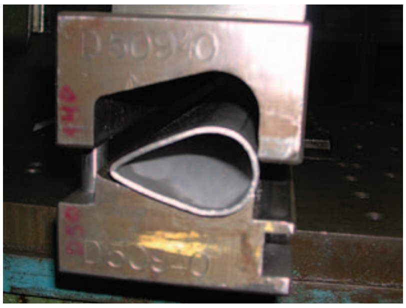
Building on Technology

Let's take a look at how shaped tubes can enhance a frames performance. First, consider the various performance characteristics desired of the frame. Obviously, light weight is desirable; the bottom bracket should be stiff; the frame should feel lively and not beat the rider to death. So how can changing the shape of tubing help?

If care is taken in how the



Tube diameter is modified using a swaging process.



Tubes cross sections can be changed by pressing them in a die.

shapes are oriented, level-two tubes can help optimize the design of the frame. By flaring a tube at the ends, joint strength and stiffness can be increased, thereby helping the stresses flow down the tube towards the more compliant middle. With careful use of ovalization in certain areas bottom bracket stiffness can be enhanced. Now bicycle frames can be customized for specific applications and rider preferences in ways never before possible.

Frames engineered with these great, new technologies are truly the next generation and a joy to ride.