

INDUSTRIAL HEATING

Heat & Corrosion Resistant Materials/Composites

C/C Composite Springs and Their Applications

C/C composites are being used in a range of heat-treatment fields, while carbon spring technology is expected to further improve production efficiency.

By Hirotaka Nagao

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Carbon-fiber-reinforced carbon composite (C/C) materials have several times the strength and elastic modulus of conventional carbon and graphite materials and offer excellent heat resistance, abrasion resistance and toughness. C/C composites have been widely used in the nose caps and

wing leading edges of spacecraft, heat-resistant parts of jet engines and gas turbines, and aircraft brake materials.

C/C composites had already appeared in the world in the 1960s and had begun finding practical use in the previously mentioned applications by the 1980s. Despite this, they have not been widely used in general industrial applications. However, the current price range is fully within the scope of use in general industrial applications. As a substitute material for graphite and heat-resistant steel, use of C/C composites is expanding in the heat-treatment field both domestically and globally.

Springs in the Heat-Treatment Industry

Coil springs are used as mechanical elements in various machines, devices or mechanisms and have become indispensable and important parts in daily household items, industrial goods and other fields. Conventional coil springs are generally made of metal, but metal coil springs have poor heat resistance and are difficult to use at high temperatures.

For example, a so-called heat-resistant alloy has a maximum temperature of 752°F (400°C). Moreover, even super-heat-resistant alloys such as Inconel and Hastelloy lose strength and deform significantly at temperatures above 1292°F (700°C), making it impossible to use them as springs in such environments. In addition, since some types of metal coil springs are easily magnetized, they cannot be used in an environment affected by magnetism.

On the other hand, ceramic coil springs, such as silicon nitride and zirconia, have superior heat resistance and corrosion resistance when compared to metal coil springs, but they are vulnerable to thermal shock and break when repeatedly used at temperatures exceeding 1832°F (1000°C). Ceramic coil springs also have the drawback of being fragile and difficult to handle due to a lack of toughness.

C/C Composite Springs

In recent years, automobiles and aircraft have been reduced in weight to improve fuel efficiency. Various industrial machines also require light spring materials to replace metals for various purposes.

A solution to these problems is the use of C/C composite springs. There are C/C composite coil springs that are made by cutting two-dimensionally reinforced long-fiber-reinforced C/C composite blocks. However, there was a drawback. The fiber was segmented during processing, and it was not possible to exhibit sufficient strength. This meant the spring constant was likely to decrease in repeated use in hot conditions.

To compensate for these drawbacks, a C/C composite spring of a type in which long carbon fibers are spirally continuous in one direction and not segmented has been proposed. Since the fibers of this spring are continuous and can fully demonstrate its role as a reinforcing fiber, it is a product that maintains a stable spring constant ... even after repeated use in hot conditions.



Fig. 1. A C/C composite coil spring with continuous spiral carbon fiber maintains a stable spring constant even after repeated use in hot conditions.

The advantages of using a brazing fixture equipped with C/C composite spring are as follows.

- Total weight reduction and improved productivity: This eliminates the need for dead weights and improves thermal efficiency, leading to energy savings.
- Improved operational efficiency: Using lightweight C/C coil springs instead of heavy dead weights not only saves energy but also improves the working environment and the performance of manufacturing operators.
- Reduction of defect rate: Radiant heat is no longer blocked by a large weight, leading to a reduction in the defect rate.
- Longer lifespan: Since there is no thermal deformation of the metal weight itself, there is no worry about unbalanced loads, leading to longer life.
- Increase in total production volume: It is possible to increase the total load of the parts processed by overwhelmingly reducing the weight of the fixture.

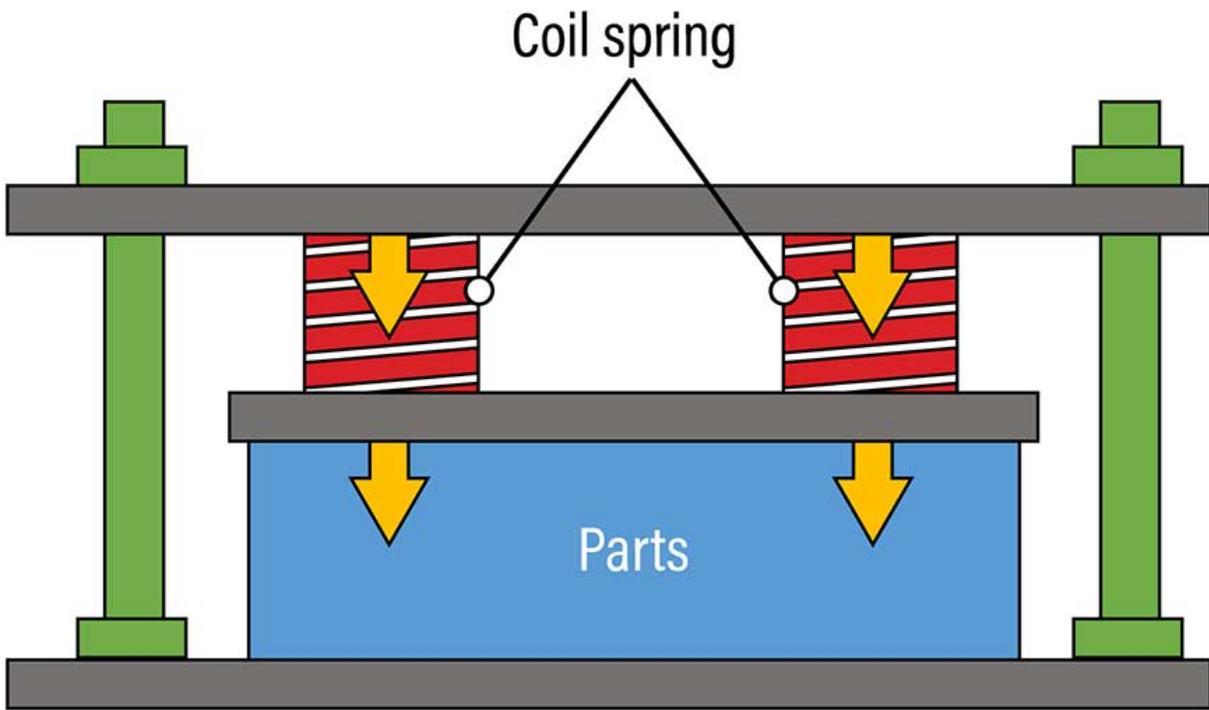


Fig. 2. Example of a C/C composite coil spring

New Type of C/C Composite Spring: Z-Type Spring

The long-fiber continuous C/C composite coil springs described do have the disadvantage that it is difficult to neatly arrange the long fibers in a spiral shape, making them unsuitable for mass production. Since the spring size depends on the size of the mold, it has been difficult to produce a variety of spring sizes and strengths.

To compensate for these drawbacks, a spring having a high shear modulus that can support a large load with a simpler manufacturing process and mass production has been developed. Instead of a coiled-version spring, a plate-shaped spring was fabricated in a zig-zag pattern using a C/C composite.

Instead of a unidirectional reinforced C/C composite material, in which the carbon fibers are aligned in one direction in the plane of the plate, short carbon fibers were used as the reinforcing material and randomly oriented in the plane in a layered manner. It was found that the in-plane shear modulus of a two-dimensional randomly oriented C/C composite was dramatically improved, so this fiber orientation may be applied as a material for a plate spring machined in a Z-shape.

As a result of the configuration described, the Z-spring can be used repeatedly even in high-temperature environments exceeding 1832°F (1000°C). It has become possible to produce a spring having a high shear elastic modulus capable of supporting a large load.

Figure 3 shows a representative example of a plate-shaped spring having a Z-shaped structure. This figure shows a C/C composite plate spring machined in a Z-shape by water-jet processing from a C/C composite laminate plate in which short-fiber carbon fibers are randomly oriented in a two-dimensional fashion.



Fig. 3. Representative example of a plate-shaped spring having a Z-shaped structure (left); C/C composite plate spring machined in a Z-shape by water-jet processing (right).

In Fig. 3, the Z-axis direction indicates the direction in which sheet-like interlayer materials and carbon fibers are randomly oriented two-dimensionally and laminated. In the molded C/C composite laminate, the short fibrous carbon fibers are randomly oriented two dimensionally in the XY plane, but the short fibrous carbon fibers are not arranged in the Z-axis direction.



Fig. 4. Example of a Z-type C/C composite spring brazing fixture

Therefore, by giving directionality as shown in Fig. 3, a plate-shaped spring machined in a serpentine shape in the XY-axis plane and having a predetermined width in the Z-axis direction can be obtained. Since such a processing method can be adopted, if a laminate made of C/C composite with a predetermined size is manufactured, it became possible to mass-produce plate-shaped springs machined in a zig-zag shape by machining.

When such a plate spring machined in a Z-shape is used as a compression spring or a tension spring, the load-deflection characteristics of the plate spring are determined by the bending stiffness (the bending stiffness is determined by the tensile modulus of each material plate) and the shear stiffness. In both cases, we were able to achieve a high load and a large deflection allowance that could not be achieved with coil-shaped C/C composite springs.

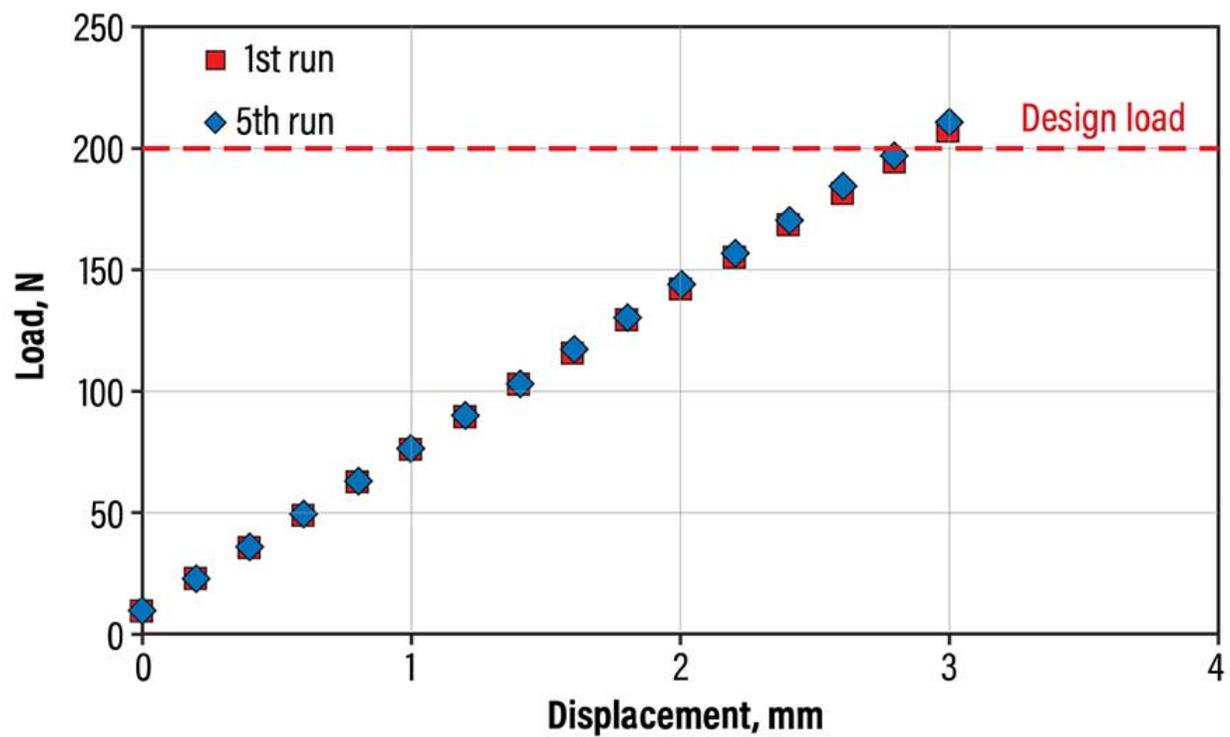


Fig. 5. The displacement-load curve of the Z-type C/C composite spring. Satisfactory spring characteristics are exhibited, even in repeated load tests.

Spring Characteristics of Z-Type C/C Composite Springs

Figure 5 shows the displacement-load curve of the Z-type C/C composite spring. From this figure, satisfactory spring characteristics are exhibited, even in repeated load tests.

After heating the Z-type C/C composite spring in a compressed state using bolts and nuts at 2282°F (1250°C) for 30 minutes in a nitrogen atmosphere (Fig. 6), the spring characteristics were measured at room temperature and a repeated heating test was performed.



Fig. 6. A high-temperature load test cycle of Z-type C/C composite spring

Figure 7 shows the change in the natural length. A decrease of about 1% in the natural length was observed only during the first heating run. However, the natural length did not change even if the heating was repeated after, and it was found that there was no setting at all.

Compared to coil-type C/C composite springs, C/C composite springs made from short-fiber reinforcing materials are characterized by very few shape restrictions and various configurations are achievable.

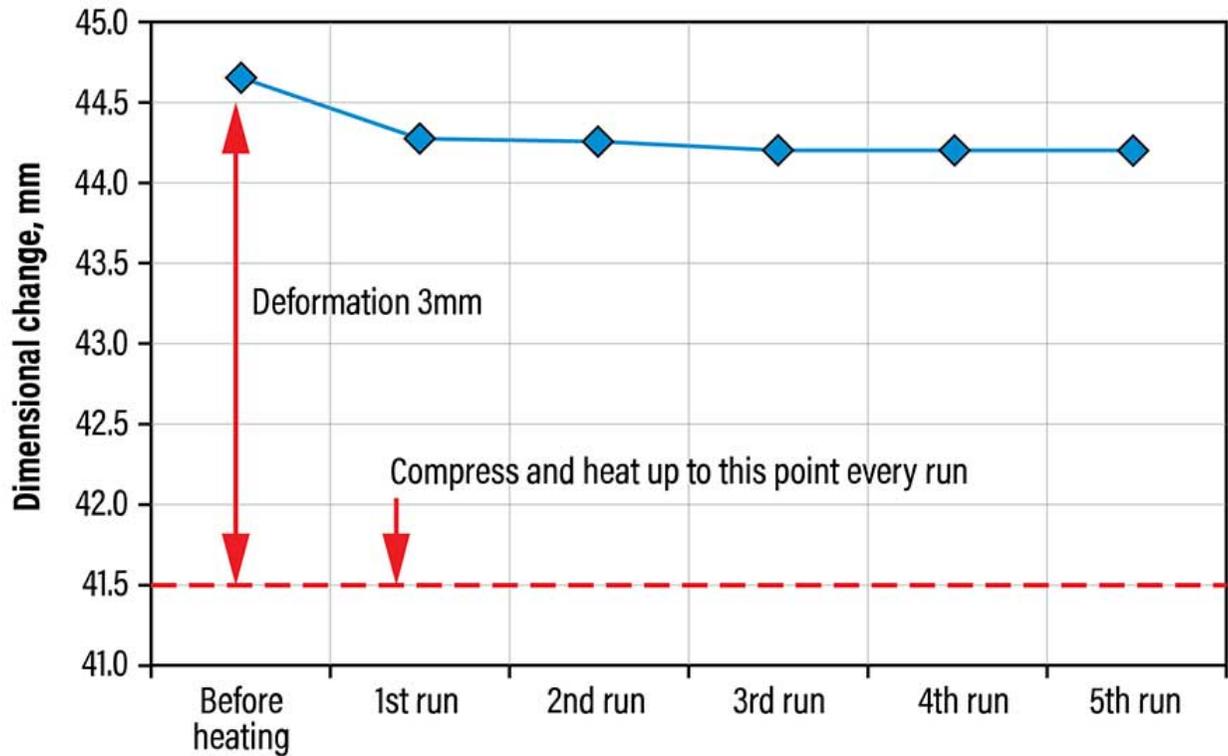


Fig. 7. Change in natural length due to repeated load tests at 2282°F (1250°C)

Application Examples of C/C Composite Springs Made from Short-Fiber Reinforcement

The C/C composite Z-type spring described until now required various other parts and components to fixture to the workpiece, as shown in previous figures. The C/C clip was developed to avoid this complexity.

By pressing the opposite ends of the opening, the C/C clip opens as shown in Fig. 8. By sandwiching the parts in this portion as shown in Fig. 9, it is possible to apply a load to the parts without preparing a fixture with a complicated structure.

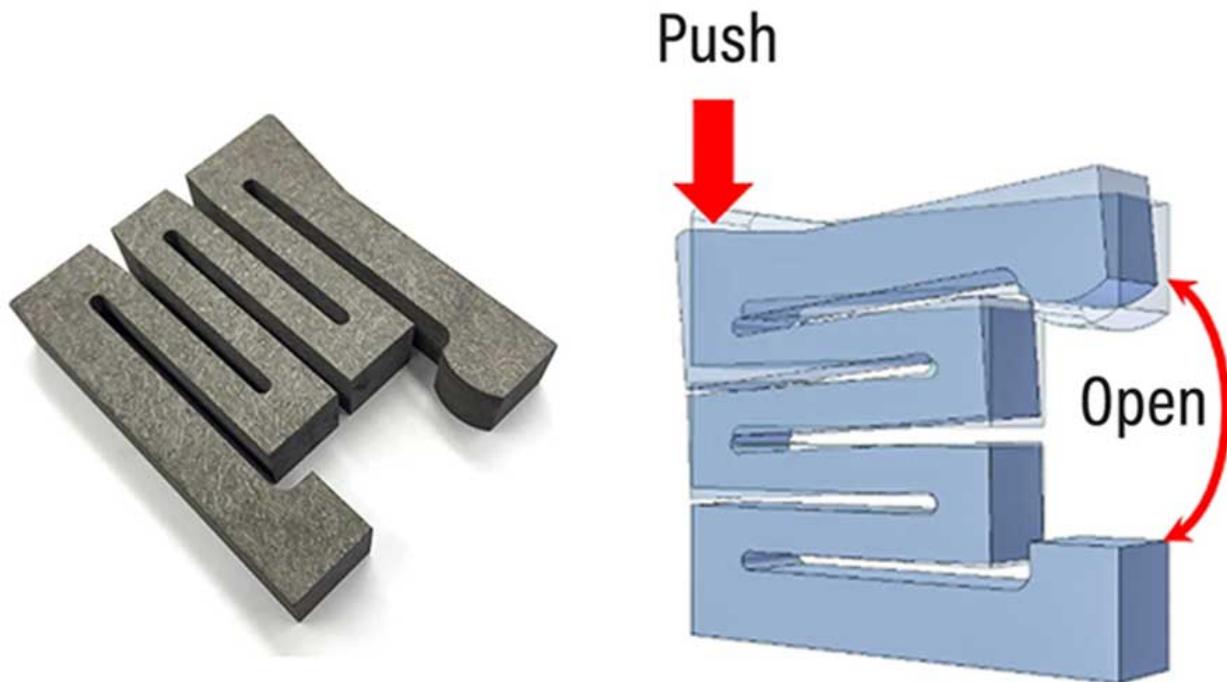


Fig. 8. The C/C composite Z-type spring required various other parts and components to fixture to the workpiece (left). The C/C clip was developed to avoid this complexity (right).

A product that combines the spring characteristics of the C/C composite Z-spring and the functions of the C/C composite bolt has been developed. The furnace, which performs heat treatment at temperatures close to 3632°F (2000°C), has electrodes and heaters made of graphite. As the size of this heating furnace increases and the size of the graphite heater increases, the deformation due to the heater's own weight increases and the deformation remains after repeated heating and cooling.

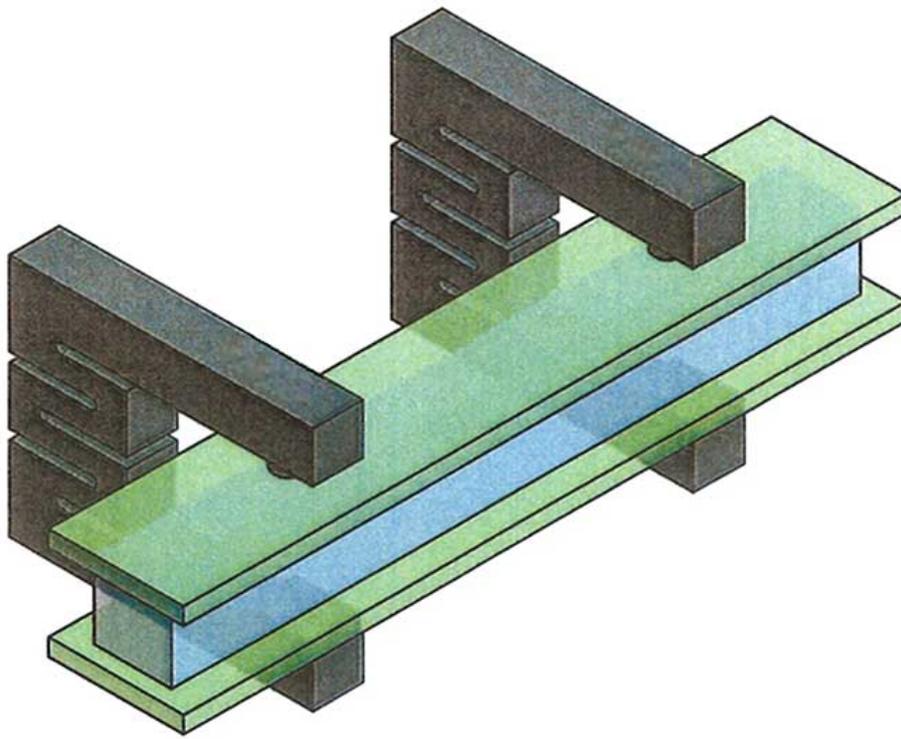


Fig. 9. By sandwiching the parts in this portion, it is possible to apply a load to the parts without preparing a fixture with a complicated structure.

As a method to reduce this deflection, it is possible to make the heaters of C/C composite. Even if it is the same carbon material, however, graphite and C/C composite heat up to four times more. The difference in the coefficient of expansion and the thermal stress caused by this difference cannot be endured, often resulting in failure of the joint. By using a bolt with a thermal-expansion-absorbing function as shown in Fig. 10, the notched part of the C/C bolt acts as a spring, absorbs dimensional changes due to thermal expansion and prevents damage.



Fig. 10. By using a bolt with a thermal-expansion-absorbing function, the notched part of the C/C bolt acts as a spring, absorbs dimensional changes due to thermal expansion and prevents damage.

As mentioned previously, conventional coil-shaped C/C composite springs were limited in size due to molding limitations. Various C/C composite spring sizes can be manufactured from fiber-reinforced materials as long as the material plate is prepared and is within the size of the plate.



Fig. 11. Example of a Z-spring with a large serpentine shape that could not be realized with a coil-shaped spring

Figure 11 is an example of a Z-spring with a large serpentine shape that could not be realized with a coil-shaped spring, while Fig. 12 shows the load-displacement curve of this spring. Satisfactory spring characteristics are exhibited even when the natural length of 9 inches (230 mm) is deflected by 2 inches (50 mm), which corresponds to 22% of the natural length.

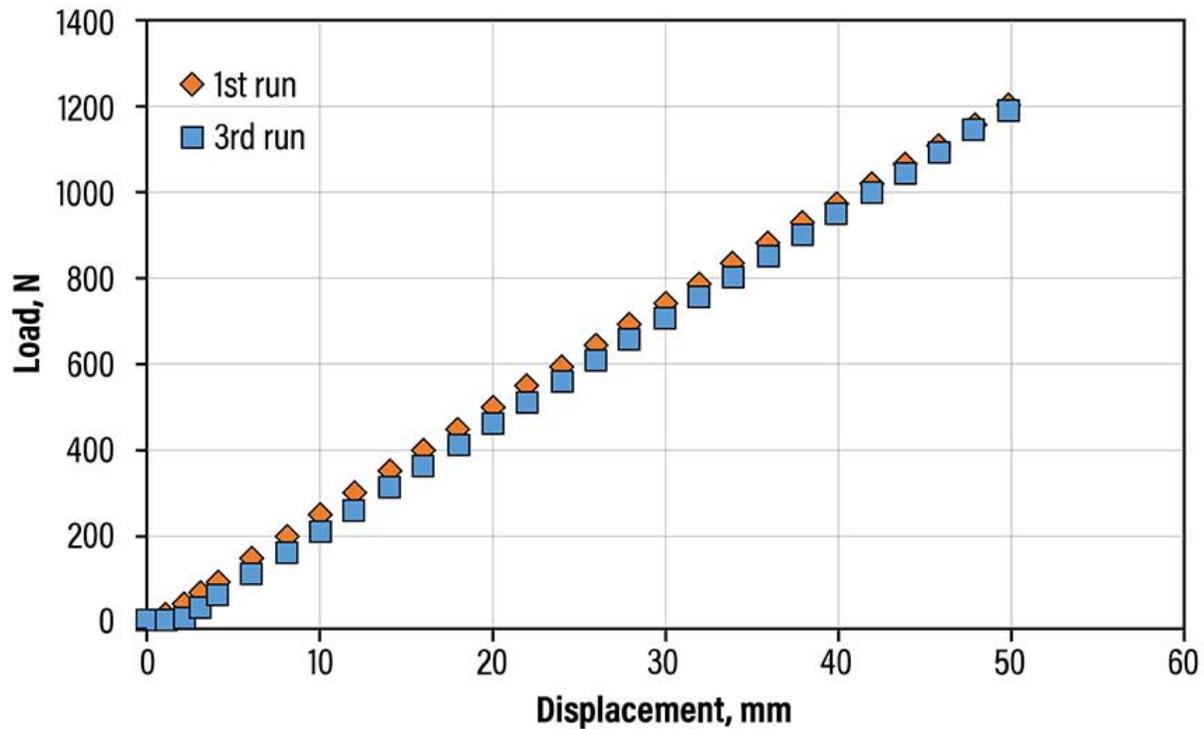


Fig. 12. Load-displacement curve of a large Z-spring

Conclusion

In the heat-treatment field and especially in brazing, from the viewpoint of thermal efficiency, the use of weights with actual loads has shifted to using heat-resistant metal springs and ceramic springs. With the emergence of C/C composite springs made from short fiber-reinforcing materials, it is assumed that C/C composites will be used in a wider range of heat-treatment fields, while the use of this carbon spring technology is expected to further improve production efficiency.

For more information: Contact Lloyd Nagamine, sales engineer, Across USA/CFC Design Inc., 1480 Beachey Place, Carson, Calif., 90746. He can be reached at 310-635-3555 or nagamine@acrosscc.com. Visit Across USA at www.acrosscc.com.

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