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HEAT & CORROSION RESISTANT MATERIALS/COMPOSITES:

Finite Element Analysis of Wire Shape

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Finite Element Analysis of Wire Shape Used to Improve Service Life of Mesh-Type Furnace Belts

WIRE MESH FURNACE BELTS ARE USED IN A WIDE VARIETY OF INDUSTRIES. IN HEAT TREATING, THESE BELTS ARE EXPOSED TO HARSH ENVIRONMENTS, INCLUDING ELEVATED TEMPERATURES AND CORROSIVE ATMOSPHERES. THIS ARTICLE, BASED ON A PRESENTATION AT THE 2000 INTERNATIONAL CONFERENCE ON POWDER METALLURGY AND PARTICULATE MATERIALS, NEW YORK, NY, SPONSORED BY THE METAL POWDER INDUSTRIES FEDERATION, DISCUSSES THE EFFECT OF USING ROUND VERSUS FLATTENED WIRE ON THE ELONGATION AND STRESS IN WIRE MESH BELTS AS DETERMINED BY FINITE ELEMENT ANALYSIS (FEM). THE INTERACTION BETWEEN THE VARIOUS SHAPED CONTACT REGIONS AND VARIOUS SHAPED WIRES IS EXAMINED.

The most important factor of mesh belt performance is service life because increasing service life will reduce annual belt costs and minimize production down time for customers. For that reason, a study was initiated as part of an ongoing research effort to improve the performance of wire mesh belts used in heat treating furnaces.

The sintering process is typically conducted at 70 to 90% of the melting temperature of the green parts. Thus, the furnace belts can be exposed to temperatures up to 2100°F. In addition to the elevated temperatures, the belts are exposed to a corrosive, generated atmosphere consisting of roughly 97% nitrogen and 3% hydrogen. This atmosphere causes deterioration of the belt properties.

The researchers were interested in determining if changing the shape of the wire used to produce spiral loops would improve their belts—specifically, if there were any benefits to using flattened wire over round wire with respect to elongation and stress in the spiral loops. This is an issue debated often in the sintering industry. Experience had shown that lowering the initial stretch and stress level in the belts increases the service life. The goal of this research effort is to study the effect of using round versus flattened wire on the elongation and stress in wire mesh belts.

MATERIALS

The chosen belt specification was one typically used in the sintering process of the powder metal industry. Fig. 1 shows a section of a typical balanced woven wire mesh furnace belt prior to being put into service. The belt is constructed by forming wire into elongated coiled spirals and then tying the spirals together with cross rods (Figs. 2 and 3). This study used a furnace belt commonly referred to as a B-36-10-8-10. It is a balance weave, which means the belt is assembled with alternating left and right hand spirals. The belt has 36 loops per foot of width and 10 loops (or cross rods) per foot of length. The connecting rods and spiral loops were made from 8- and 10-gauge 314 stainless steel alloy wire, respectively. These belts are typically two to four feet wide and the lengths vary.

The analyses used the material properties of 310 stainless steel at 2000°F instead of 314 stainless steel alloy due to the lack of material properties for

Fig. 1 Typical balanced woven wire mesh furnace belt.

Fig. 2 Woven wire mesh belt spiral loops and connecting rod.

Fig. 3 An assembled mesh belt link.

Fig. 1

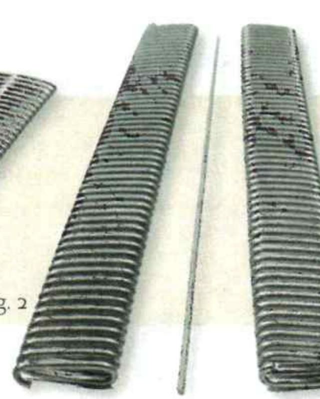

Fig. 2

Fig. 3

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314 stainless steel alloy at 2000°F. The Nickel Development Institute felt that the mechanical properties of 310 stainless steel would be similar to 314 stainless steel alloy at elevated temperatures. A Young's Modulus of 8.40 x 10^6 psi and a Poisson's Ratio of 0.27,[2] along with area properties listed in Table I, were used for the linear analyses.

Table I Cross Sectional Area Properties

	ROUND WIRE	FLATTENED WIRE
Height (in.)	0.1350	0.1105
Width (in.)	0.1350	0.1434
θ	N/A	9.75°
Area (in.^{2})	0.01431	0.01431
Iyy (in.^{4})	1.630 x 10^{-5}	2.061 x 10^{-5}
Izz (in.^{4})	1.630 x 10^{-5}	1.329 x 10^{-5}

PRELIMINARY DATA

WIRE CROSS-SECTION MEASUREMENTS

Both the round and flattened spiral loops were made from 10-gauge wire having a diameter of 0.135 in. A sample of some flattened wire was measured using an optical-comparator equipped with a computer data acquisition system. This data was used in developing a representative flattened cross section (Fig. 4) to be used in the finite element analyses. The shape was scaled so that it would have the same cross-sectional area as a 10-gauge wire.

Table I gives the cross-sectional area properties that were used for the beam-element analysis. The thickness of the belt was assumed to be 0.500 in. for both the round and flattened spirals. This is the nominal thickness for this type of belt presently being produced.

FLATTENED WIRE TWIST MEASUREMENTS

In addition, the weaving process causes the flattened spiral to have some degree of twist. The integrity of the interface between the flattened wire spiral and the connecting rod is dependent on this angle of twist.

A B-36-10-8-10 belt was used for both the round wire spiral and flattened wire spiral measurements. The actual belt used for the flattened wire twist measurements was slightly different from the modeled belt in that it had flattened seats formed into the connecting wire.

Figs. 5a and 5b show the spiral/cross rod configurations in the belt specimens. The measurements acquired from the optical comparator indicated a large variance in twist angle for the flattened wire specimen with a maximum twist angle of 9.75 degrees and a maximum gap of 0.0301 inches between the spiral and connecting rod. The round wire spiral/round connecting rod configuration produces a robust interface that is not sensitive to twist. This specimen had a very uniform appearance with a maximum gap measuring about 0.0206 inches (it should be noted that there were very few gaps in the round wire assembly).

The large amount of twist variance for the flattened wire makes it difficult to model this situation. A statistical analysis could be performed to determine the average angle of twist. The finite element analyses were conducted using a 9.75 degree twist angle.

MODELS

A single spiral loop being loaded by a connecting rod was modeled using ANSYS finite element software. The results were used to determine the relative behavior between the round and flattened spiral wire belts. A step-by-step approach was taken in this analysis, starting with simpler three dimensional (3-D) beam element models with linear material properties to obtain some baseline information and working up to 3-D solid models with nonlinear material properties and contact elements.

Solid models were made first using solid elements with pressure loading and linear material properties, and then were made using contact elements with nonlinear material properties. With each step, the results were compared with the previous step.

A static analysis was used because the conveyor for sintering processes runs at a constant velocity. Also, it was assumed that the loading and unloading of parts did not create any dynamic effects on the tension of the belt. Because the wire mesh furnace belt is constructed from a series of elongated coiled spirals tied together by cross rods, only one loop of the spiral was considered in

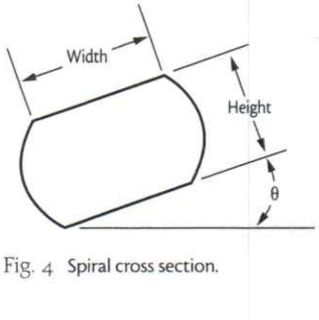

Fig. 4 Spiral cross section.

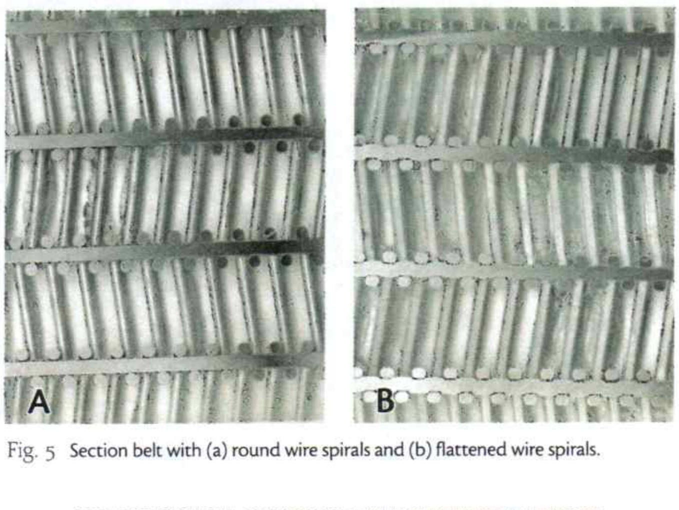

Fig. 5 Section belt with (a) round wire spirals and (b) flattened wire spirals.

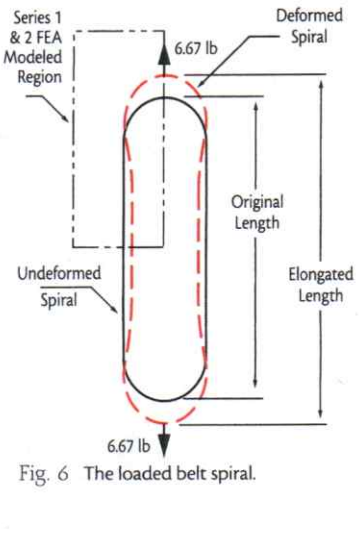

Fig. 6 The loaded belt spiral.

the model. Also, only one-quarter of the spiral needs to be modeled due to symmetry.

The belt tension in a sintering furnace varies between the entrance and the exit and can vary from furnace-to-furnace. It can be nearly zero pounds at the entrance up to a design load of 240 pounds per linear foot of belt width. This analysis used a design value of 240 pounds per linear foot of belt width divided among the 36 spirals in a foot of belt width resulting in 6.67 pounds of tensile force on each spiral loop (Fig. 6).

SERIES 1: BASELINE MODEL

The wire spiral loops were first modeled using 3-D structural beam elements with two nodes and six degrees of freedom (translation in the x, y, and z, and rotation about x, y, and z axes) per node. The results from these models were used as baseline data or data to compare sequential models. A one-quarter symmetric model was made of the round and flattened spiral wire loops and is shown in Fig. 7. Symmetric boundary conditions were applied at both ends of the spiral and a 3.33-pound point load (one-half of 6.67 full loop load) was applied to the top of the spiral.

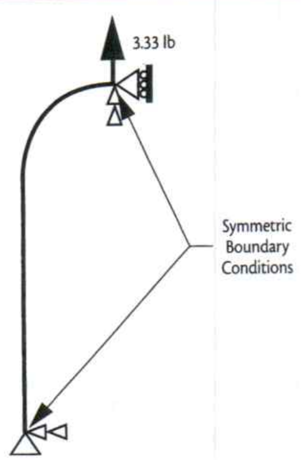

Fig. 7 Series 1 boundary conditions.

SERIES 2: SOLID MODEL/LINEAR MATERIAL/ PRESSURE LOADING

This model series consists of three-dimensional, structural solid models meshed with brick-type elements of round and flattened wire mesh furnace belt spirals. These models were used as a stepping stone between the structural beam element models with a point load and the solid model using contact elements with nonlinear material properties. The eight-node elements were hexagonal shape solids with three degrees of freedom (translation in the x, y, and z) per node utilizing the quarter symmetry as shown in Fig. 7. Figs. 8a and 8b show the models for this series.

Symmetric boundary conditions were applied at both ends of the spiral portion of the model. These models were loaded by applying pressure to one face of an element located at the end of the curve portion of the spiral. The pressure produced a net force of 1.67 pounds.

SERIES 3: SOLID MODEL WITH NON-LINEAR MATERIAL PROPERTIES LOADED BY CONNECTING ROD

This series modeled the contact surface interaction between the round and flattened spiral with a round connecting rod. Solid models were created of the top portion of the spiral for both wire types. The models for this series (shown in Figs. 9a and 9b) were con-

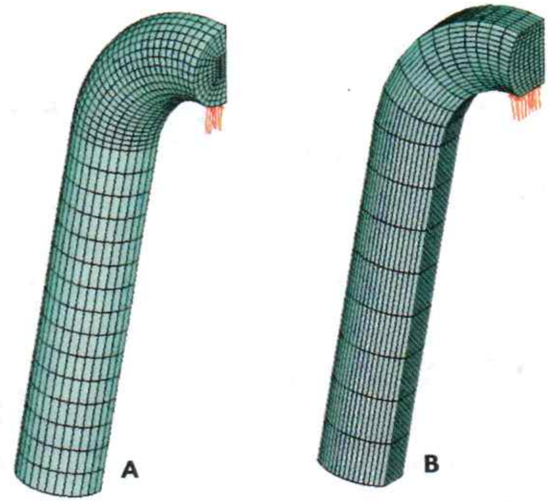

Fig. 8 Solid model of (a) round spiral with pressure load and (b) flattened spiral with pressure load.

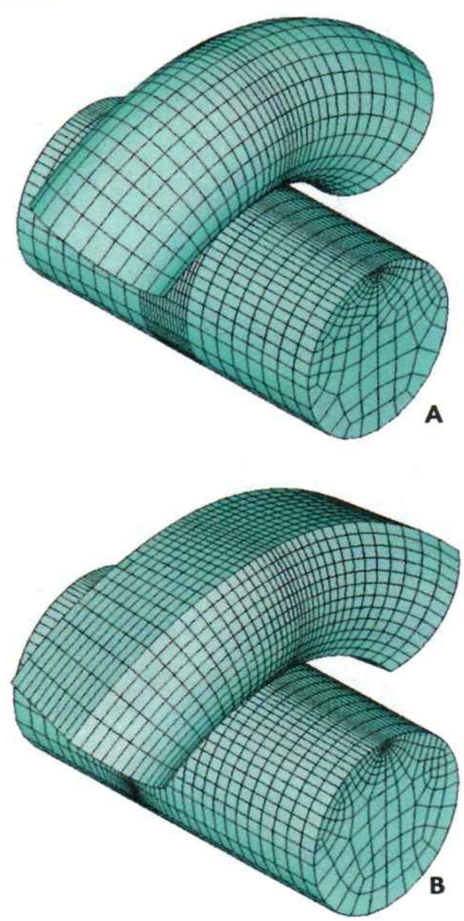

Fig. 9 Solid model of (a) round spiral and connecting rod and (b) flattened spiral and connecting rod.

Table II **Series 1 Baseline Results**

SPIRAL TYPE	SPIRAL ELONGATION (IN.)	NORMAL STRESS (PSI)
Round (R)	2.62×10^{-4}	2,689
Flattened (F)	3.40×10^{-4}	3,378
ΔF/R	30%	25%

Table III **Series 2 Solid Model with Linear Material and Pressure Loading**

SPIRAL TYPE	SPIRAL ELONGATION (IN.)	NORMAL STRESS (σ_X) (PSI)	VON MISES STRESS (σ_E) (PSI)
Round (R)	2.45×10^{-4}	2,733	1,424
Flattened (F)	3.10×10^{-4}	2,889	2,047
ΔF/R	27%	6%	44%

Table IV **Series 3 Model Contact Interface Results**

SPIRAL TYPE	VON MISES STRESS (σ_E) (PSI)	ELONGATION CAUSED BY CONTACT INTERFACE (IN.)
Round (*R*)	8,922	8.46×10^{-4}
Flattened (*F*)	12,768	2.65×10^{-3}
ΔF/R	43%	213%

Table V **Overall Furnace Belt Behavior**

SPIRAL TYPE	SPIRAL ELONGATION (IN.)	ELONGATION CAUSED BY CONTACT INTERFACE (IN.)	ELONGATION OF BELT (IN./FT. OF BELT LENGTH)
Round (R)	2.45×10^{-4}	8.46×10^{-4}	1.09×10^{-2}
Flattened (F)	3.10×10^{-4}	2.65×10^{-3}	2.96×10^{-2}
ΔF/R	27%	213%	172%

structed using the same three-dimensional structural solids elements used in Series 2. The continuity between the connecting and spiral wires was modeled using surface contact elements. Symmetric boundary conditions were applied at both ends of the spiral portion of the model. These models were loaded by applying 3.33 pounds of force divided among the nodes on each end of the connecting rod. This produced a net force of 6.67 pounds of tension on the spiral. The nonlinear material properties for 310 stainless steel at 2000°F and the cross-sectional properties (Table I) were used for this series.

RESULTS

SERIES 1 RESULTS

Small and large deflection analyses were conducted, however, no significant differences were found. Table II contains a summary of the results from this series. The results in the table show that the flattened wire spiral had a 25% higher stress level and elongated 30% more than the round spiral wire.

SERIES 2 RESULTS

The normal stress (sx) and the spiral elongation results from this series (Table III) are within 6% and 9%, respectively, of the results from Series 1. The spiral elongation was considered to be twice the displacement of the node located at the top center of the spiral loop. The elongation of the flattened wire spiral was 27% greater than the round wire spiral. In this series, there was no significant difference in the normal stress; however, the von Mises stress for the flattened wire was 44% higher than the round wire.

SERIES 3 RESULTS

The maximum von Mises stress and the elongation caused by the spiral and connecting wire interface are shown in Table IV. It can be seen that there are significant differences in elongation and stress between the two configurations. Figs. 10a and 10b show contour plots of stresses for the two configurations. When compared to the round spiral, the corner of the flattened spiral digs into the spiral resulting in a large displacement and a stress 43% increase in stress.

OVERALL FURNACE BELT ELONGATION

The overall furnace belt elongation can be obtained by combining the results from Series 2 and 3. Table V shows initial elongation of a belt made with round and flattened spirals to be 1.09 x 10-2 in./ft. and 2.96 x 10-2 in./ft., respectively. In other words, a belt produced with a flattened wire spiral is expected to elongate 172% more than a belt made with round wire.

CONCLUSION

The finite element analysis has helped to further the understanding of wire mesh conveyor belts. The measurement results show that belts made with flattened wire spirals are likely to be twisted and the angle of twist can be as

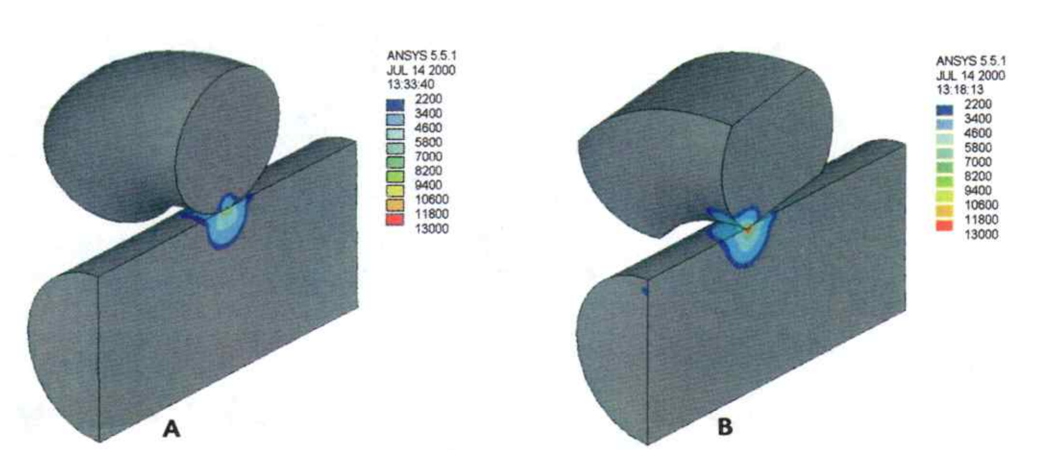

Fig. 10 Von Mises stress of (a) round spiral loaded connecting rod and (b) flattened spiral loaded connecting rod.

great as 9.75 degrees. Results also showed the elongation to be 172% more and stress in the contact region to be 43% higher for belts made with flattened wire spirals rather than round wire spirals. This study did not take creep into consideration. Further studies are planned to include creep into the model. IH

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ACKNOWLEDGMENTS

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FROM THE MANUFACTURER

There are many components which affect the performance of a wire woven belt. Along with the geometry, material selection and manufacturing techniques are critical elements.

W.M.P. continues to partner with Special Metals Corp. in the development of exotic test alloys. Other materials have been modified to provide greater belt life. Some of there materials are designed to perform up to 2300 °F.

The belts are woven using special tooling and the wire is slowly drawn onto the blade with custom-made machines. This creates the lowest spiral ID in the industry. Lower spirals equal less stretch. Moreover, as belts stretch the grain structure changes and internal ruptures or voids develop. These voids allow for penetration of other elements and lead to premature belt failure.

Wire-Mesh Products combines round wire geometry, state of the art materials, and low spiral profile manufacturing to maximize belt life. **THERE IS A DIFFERENCE.**