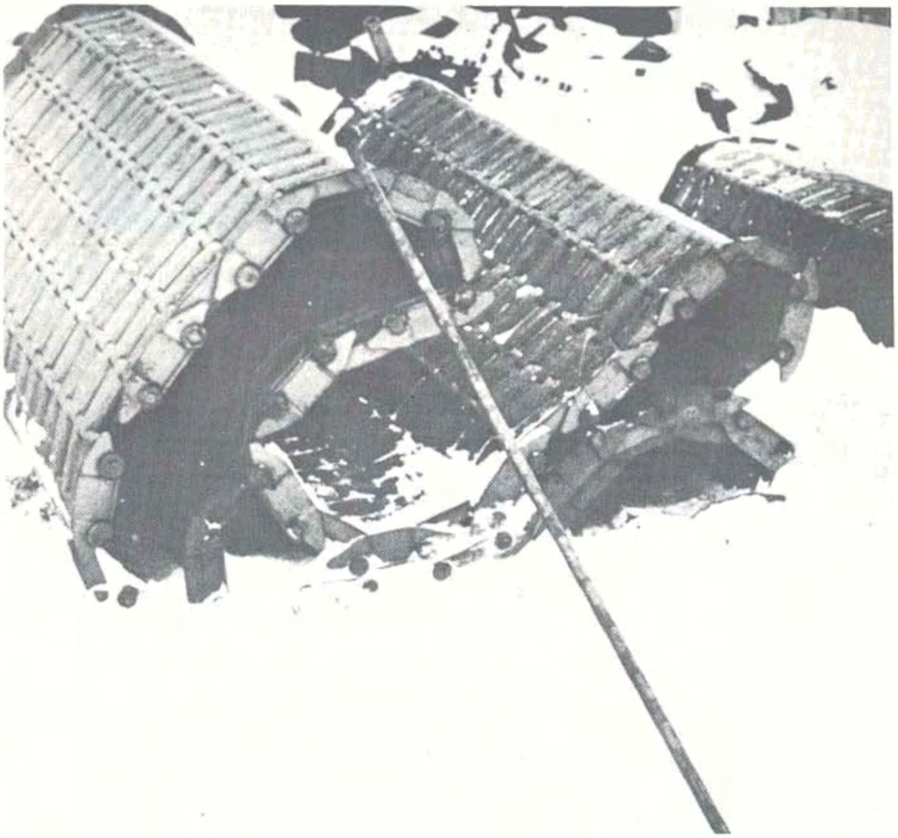
Analyzing Belt Pin Failures

Integral components of furnace link belts, belt pins fail by distortion and fatigue. Apparent causes of premature failure include annealing and grain size variations.

By BRUCE McLEOD

Fig. 1 — This belt pin, of RA 330-HC, became severely distorted during a year's service in a stress relieving operation at about 1,650 F under a loading of approximately 16 lb per sq ft. Micro (250×) shows massive carbides; compare with Fig. 2.

Fig. 2 — Though representing the same heat of material in the same application as the pin of Fig. 1, this pin was only slightly deformed ("crankshafted") after the same year of service. The cause is attributed to a different annealing cycle — unlike the pin of Fig. 1, this pin had fine, well dispersed carbides, shown at 250× in the micro.



Belt pins of RA 333-SA are still straight even though the belt had to be scrapped. It served more than five years in a furnace operated between 1,550 and 1,650 F.

In heat treating furnaces, link belts often fail because the pins distort, opening gaps between links, into which small parts become wedged. This distortion, called "crankshafting" (Fig. 1), is affected by the following conditions:

- Annealing times, temperatures, and quench method — they affect carbide distribution in belt pin alloys.
- Grain size — depending upon the strengthening mechanism, an optimum grain size may be reached, beyond which coarser grains do not necessarily add shear strength or resistance to crankshafting. In fact, a coarser grain material may fail more rapidly by mechanical fatigue.
- Alloy content — a highly alloyed material (such as RA 333-SA) will resist crankshafting better than other heat resisting alloy materials regardless of their grain size.

What Causes Distortion?

Distortion of belt pins results primarily from creep in shear which occurs between adjacent links. Shear loading produces about the same degree of creep at approximately one-half the stress level that would be required to cause creep with longitudinal loading. Belt pins, as a consequence, are more susceptible to creep than the links themselves, which are stressed in tension.

During each cycle through a fur-

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Fig. 3 — This belt pin apparently failed because of mechanical fatigue. Note crack midway along the bar. This pin was cleaned by pickling.

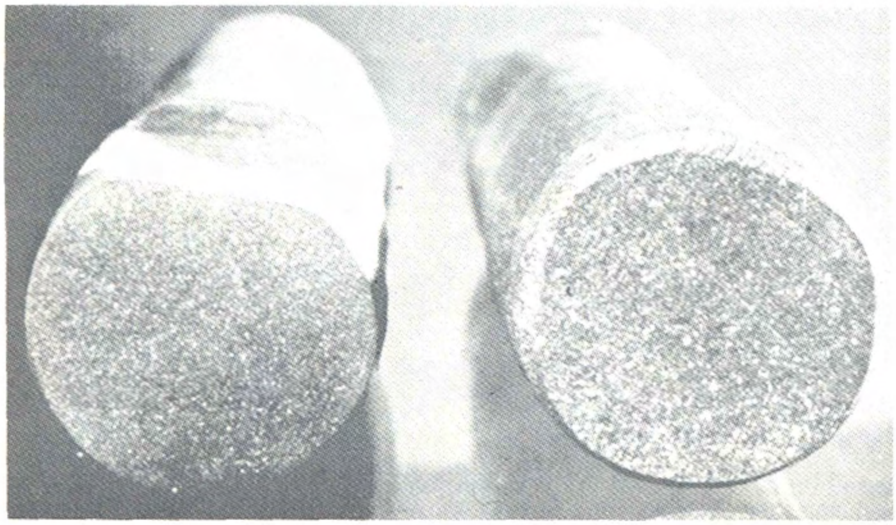

Fig. 4 — These two pins have different grain sizes. The coarse-grained stock (right) has a slightly lower nickel content, 32%. Etchant, 50% HCl in water (160 F); approx. 2×.

nace, shear stresses acting on a belt pin will vary greatly. These stresses can be small, resulting only from the weight of the links after the belt passes the discharge end of the furnace (assuming proper belt catenary).

In the belt zone which is just about to engage the drive drum, however, stresses will be many times greater due to the force required to pull both the belt and the work load extending back many feet into the furnace. This cumulative loading is regarded as being primarily responsible for crankshafting.

A heat-resisting alloy commonly used for belt pins to join cast link belts together is RA 330-HC (35 Ni, 19 Cr, 1.25 Si, and 0.40 C). This higher carbon content variation of RA 330 (ASTM B-511) provides great strength at temperature, and closely matches the composition of popular cast-link alloys, such as ACI (Alloy Casting Institute) HT and HU. Although this composition has been used for belt pins for more than 25 years, research conducted within the past ten years has resulted in greatly improved mechanical properties.

Figure 1 illustrates an example of crankshafting. In this particular instance, a pin (¾ in. in diameter by 18 in. long) of RA 330-HC was used to pin a 60 ft belt operating with a load of about 16 lb per sq ft at approximately 1,650 F. This belt was in service for a year when severe crankshafting was observed.

When the belt was removed, observers noted that a considerable difference in the degree of crankshafting existed between various pins (Fig. 1 and 2). Also, pins having the most severe crankshafting were located at random throughout the belt. Because no pins had been replaced during the service life, there was every reason to believe that all pins had been subjected to the same service conditions.

The first step in investigating this failure was careful chemical analysis, which confirmed that all pins represented the same heat of RA 330-HC. Therefore, differences in the degree of crankshafting could certainly not be attributed to variations in composition.

Microstructural examination, however, revealed considerable difference in carbide distribution between pins. A pin with little crankshafting contained many fine dispersed carbides (Fig. 2), while a severely crankshafted pin had fewer, but more massive carbides (Fig. 1).

It is believed that the greater preponderance of finer carbides indicated a higher annealing temperature. More carbon was taken into solution at this higher temperature, resulting in greater carbide precipitation and consequent strengthening at operating temperatures.

This finding prompted research into the effect of variations in annealing procedures and carbon contents (from 0.25 to 0.50%) on elevated temperature strength, as determined by stress-rupture testing. Studies resulted in an annealing process which provided the optimum combination of strength and ductility at operating temperature; a nominal carbon content of 0.40% was also established. Consequently, the creep strength offered by RA 330-HC bars was uniformly increased.

The improved annealing process (heating at 2,150 F and water quenching) reduced failures due to crankshafting of belt pins. Ultimate failure, of course, may still be due to this cause if shear stresses are sufficient.

For more creep strength than that offered by RA 330-HC, we suggest RA 333-SA, an alloy with 45 Ni, 25 Cr, 1.25 Si, 3 Co, 3 W, and 3 Mo.

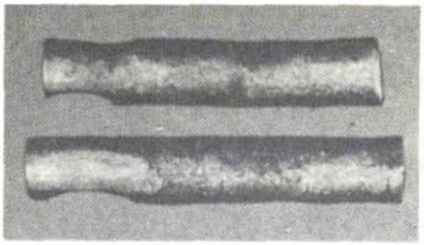

Fig. 5 — Though different in grain size, the pins of Fig. 4 exhibited practically the same degree of crankshafting in service. The lower pin has the coarser grains.

Research to determine the thermal processing required to produce optimum properties for belt pins of this alloy has been conducted; it revealed that a grain size of ASTM No. 3 to 5 would be preferred.

Mechanical Failures in Belt Pins

While most belt pins fail because of distortion, some failures occur from mechanical fatigue (Fig. 3). During a complete cycle, a belt will reach the operating temperature of the furnace, pass over the drive drum at the discharge end (which is almost always driven by teeth), return under or through the furnace, and finally pass over the idler drum to repeat the cycle.

As the belt begins to engage either drum, torsional forces may be exerted on the pin as all links in the same line turn to meet the confining contour of the drum. These links then become stressed in the opposite direction after the links have rotated 180°, and the belt leaves the drum to begin its return. The catenary of the belt on the return flight also affects stresses that may be exerted on belt pins. Bending stresses can be imposed on the pins if skid rails are used to support the belt as it passes through the top (or work) flight of the cycle.

With successive cycles, these torsional and bending stresses rise and fall, making the furnace, in effect, a slow-cycle mechanical-fatigue machine for the belt pins. These nominal stresses are magnified greatly by mechanical problems, such as misalignment or crankshafting.

Effects of Grain Size

As has been established, mechanical fatigue in low-alloy steels is affected by grain size. Some observations leading to the same conclusion have been reported for heat-resisting alloys. For example, R. R. Toolin and F. C. Hull reported (in "Fatigue Strength of Refractalloy 26 as Affected by Temperature, Hardness, and Grain Size," Proceedings, American Society for Testing Materials, Vol. 52, 1952), results of work on Refractalloy 26, a precipitation-hardening alloy containing 38 Ni, 18 Cr, 20 Co, 3.2 Mo, 2.75 Ti, and 0.20 Al. Fatigue at 1,200 F revealed that a fine-grain material of approximately ASTM No. 8 grain size exhibited about 50% more fatigue strength at 10^8 cycles than did a material having an average grain size of ASTM No. 3. From a mechanical fatigue standpoint, it should be noted that fine grains become less advantageous as testing temperatures increase to approximately 1,500 F.

Similar testing on a nickel-based alloy containing 21 Cr, 9 Mo, and 3.65 Cb + Ta indicated that, at 1,400 F and lower, material with ASTM No. 9 grain size had more rotating-beam fatigue strength than material with an ASTM No. 3.5 grain size. Testing at 1,600 F, however, revealed that this material had better mechanical-fatigue resistance, according to data in "Inconel Alloy 625," Technical Bulletin T-42, Huntington Alloy Products Div., International Nickel Co.

Although no specific fatigue data showing the effect of grain size on alloys of belt pin composition have been noted, these findings tend to indicate that resistance to mechanical fatigue is enhanced with a finer-grained material up to 1,500 F, and by coarser grains at higher temperatures.

The normal control temperature of belt furnaces ranges from 1,450 to 1,700 F. However, belts can cool during the return flight and in passing over either drive or idler drum, and also when cold stock is placed on them. Thus, some belts operate on the low side or below the processing temperature range during much of their cycle. A belt pinned with a fine-to-medium grain sized material may have better resistance to fatigue, particularly during that portion of the cycle involving contact with either idler or drive drums, where lower temperatures and severe stresses are likely to be encountered.

Other Aspects of Service Distortion

A rather obvious question arises, nonetheless, as to whether a fine-to-medium grain size would sacrifice resistance to crankshafting due to lower creep-strength even though fatigue strength is better. Figure 4 illustrates the grain size of two pins removed from a belt after a year's service at 1,650 to 1,700 F. The pin on the left is RA 330-HC with a grain size of ASTM No. 5 to 6. The other pin, of a similar composition but with a lower nickel content (32% nominal) has a grain size rated at approximately ASTM No. 1 to 2.

In Fig. 5, the same pins are shown in profile, illustrating the maximum degree of crankshafting for each. It is readily apparent that the coarse-grained material provided little, if any, extra resistance to crankshafting in this instance.

Two other instances merit discussion. In one, a belt was constructed of RA 333-SA alloy, employing pins of the same coarse-grained material noted in the prior example. It was operated at temperatures of 1,550 to 1,750 F with an average load of 16 lb per sq ft. Figure 6 illustrates three pins removed from this belt after three years' service. The two showing the least crankshafting are of RA 333-SA, with a grain size rated at ASTM No. 4. The crankshafted pin of lower alloy content has a grain size of ASTM No. 1 to 2.

In the other instance, a belt was pinned with ¾ in. in diameter RA 333-SA belt pins, and operated for 5¼ years in an air-atmosphere furnace at temperatures ranging from 1,550 to 1,650 F, being idled at 1,400 F over weekends. The average load carried was 31 lb per sq ft, and maximum loads of 50 lb per sq ft have been encountered. As the photo on p. 78 shows, the pins required no straightening or repairing during the 5¼ years of service.

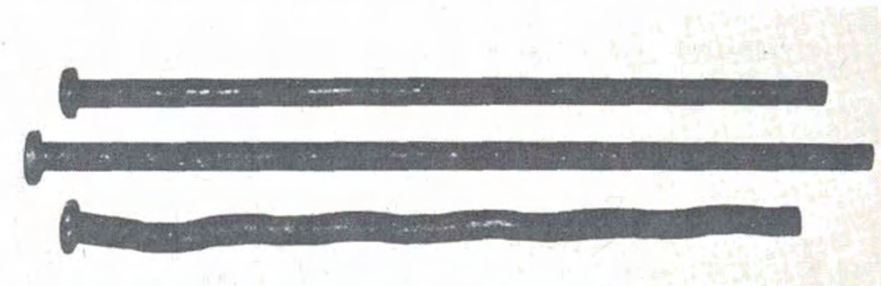

Fig. 6 — These three pins operated in the same furnace for three years at temperatures ranging between 1,550 and 1,750 F. The distorted pin (bottom) is of coarse-grained 32 Ni, 21 Cr alloy, while the other two are of RA 333-SA, a more highly alloyed material.