Carburizing of Big Module and Large Diameter Gears

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Carburized gears have higher strengths and longer lives compared with induction-hardened or quench-tempered gears. But in big module gears, carburizing heat-treatment becomes time-consuming and expensive and sometimes cannot achieve good hardness due to the big mass-effect. Also, it is not easy to reduce distortion of gears during heat treatment.

Figure 1—Conventional gas-carburizing furnaces. Maximum measurements of a gear can be 1.3 m in diameter, 2 m in height and 5,000 kg in weight. Carrier gas is endogas, enriching gas is propane.

Figure 2—New gas-carburizing furnaces. Maximum measurements of a gear can be 2.5 m in diameter, 2.5 m in height, and 15,000 kg in weight. Carrier gas is a mixture of methanol and nitrogen, enriching gas is propane.

Figure 3—Induction hardening of tooth flank only. The gear has 92 teeth, each one 405 mm long, a module of 36.4, an outside diameter of 3,115 mm and is made of SCNCrM2A, a JIS material specification.

In order to achieve good surface hardness of the carburized layer, it is necessary to precisely control the carbon content distribution. The carburizing time is much longer for big module gears due to deeper case-depth requirements. So, after carburizing, it is necessary to have intermediate cooling to less than 650°C to get finer grain size and better mechanical properties. By using a carburizing furnace equipped with a fast cooling function, workpieces can proceed through intermediate cooling and heat up again to quench temperature inside the same furnace. This can remarkably reduce the total heat-treatment time, as well as costs.

The distortion that comes from heat treatment is unavoidable. But, by improving the arrangement of a load of parts, we can reduce distortion and thereby reduce manufacturing costs.

Introduction

Surface hardening technology is very important to increasing the durability and strength of big module gears, thereby reducing the size and weight of those gears and their gear reducers and, furthermore, reducing the weight of their whole machines. But, in past years, most of the big module gears or large diameter gears were designed as either casted or welded and were heat-treated by either normalizing or through-hardening. After years of running, pitting or wear becomes serious and finally vibration and tooth breakage can happen and stop a production line.

Until recently, we at Formosa Heavy Industries Corp. of Taiwan used either carburizing or induction hardening, but the company was limited to carburizing gears with diameters of at most 1.3 m. To reduce manufacturing costs and increase the carburizing capability for big module, large diameter gears, we recently installed a new set of furnaces that can carburize gears with diameters of up to 2.5 m.

The new set of furnaces is equipped with a new carburizing process and technology in order to produce higher quality carburized gears. The computer simulation program can control the carbon content profile in order to achieve good hardness, and the fast cooling function within a nitrogen atmosphere can shorten the total heat-treatment time.

Induction Hardening

Gears with diameters bigger than a carburizing furnace should be induction-hardened. Because of the big diameters, teeth are hardened one by one. There are two ways to harden the teeth: "tooth flank hardening only" and "tooth root hardening." Figure 3 shows the treatment of tooth flank hardening, and Figure 5 shows the treatment of tooth root hardening.

Figures 4 and 6 show the macrostructure and hardness distribution curve of the hardened layers from tooth flank hardening and tooth root hardening, respectively. Figure 7 shows the tooth profile after induction hardening of the gear shown on Figure 5. That gear has been tooth root induction hardened. The result shows that the tooth pressure angle decreased slightly. Because only one tooth has been heated while the gear's other teeth remain cold during induction hardening, the geometrical accuracy and tooth lead are almost unchanged during tooth-by-tooth induction hardening.

Carburizing

Carburizing via small furnace with traditional process and carrier gas generator. Figure 8 shows the typical carburizing process of a 1.3 m furnace for about a 3 mm case depth. During carburizing, Formosa Heavy Industries uses carrier gas produced by an endogas generator. Also, the carbon potential is enriched by propane gas and controlled by an oxygen sensor. After carburizing, the workpieces must be taken out of the carburizing furnace and put into a tempering furnace for intermediate cooling, then air cooled to room temperature. After cooling, the workpieces will be painted with anti-carburizing paste, then put into the carburizing furnace again to heat up to quenching temperature. Figure 9 shows the load being taken out of the carburizing furnace, ready for quenching.

Carburizing of large diameter gears with new process furnace. Figure 10 shows the typical carburizing process for about a 5 mm case depth. The carrier gas comes from a mixture of liquid methanol and pure nitrogen. The carbon potential is measured by oxygen sensor and controlled via propane as an enriching gas and air as a diluting gas. In this case, we don't need any gas generator for our carrier gas. The carburizing, intermediate cooling and quenching procedures are continuous and don't involve taking the load out of the furnace. Figure 11 shows the load being taken out of the carburizing furnace, ready for quenching.

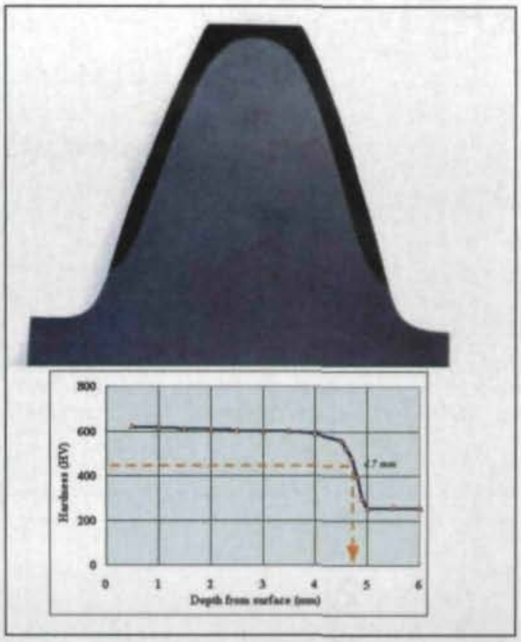

Figure 4—Test piece showing profile of tooth-flank hardened gear in Figure 3. Hardness of material before hardening: HB 250~265. Hardness of surface after hardening: HRC 52~55. Thickness of hardened layer: about 4.7 mm.

Figure 5—Induction hardening of tooth flank and root. The gear has 108 teeth, each one 182 mm long, a module of 25, an outside diameter of 2,776 mm and is made of SCM440, a JIS material specification.

Results of carburizing. Figures 12 and 13 show the macrostructure and hardness distribution of a true-sized test piece from the load shown in Figure 9 that was carburized via a 1.3 m furnace. The measured case depth is about 3.5 mm. The hardness within 0.2 mm of the surface is lower; this decarburizing effect comes from taking workpieces out of the furnace when doing intermediate cooling. Figure 14 shows the microstructure of the hardened layer; the microstructure is fully martensitic.

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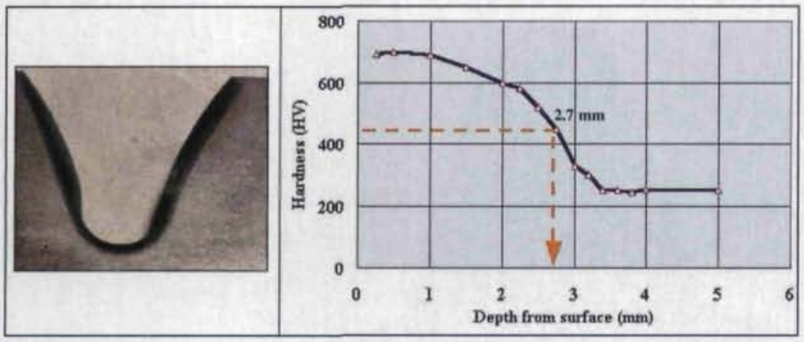

Figure 6—Test piece showing profile of tooth-root hardened gear shown in Figure 5. Hardness of material before hardening: HB 250~265. Hardness of surface after hardening: HRC 52~55. Thickness of hardened layer: about 2.7 mm.

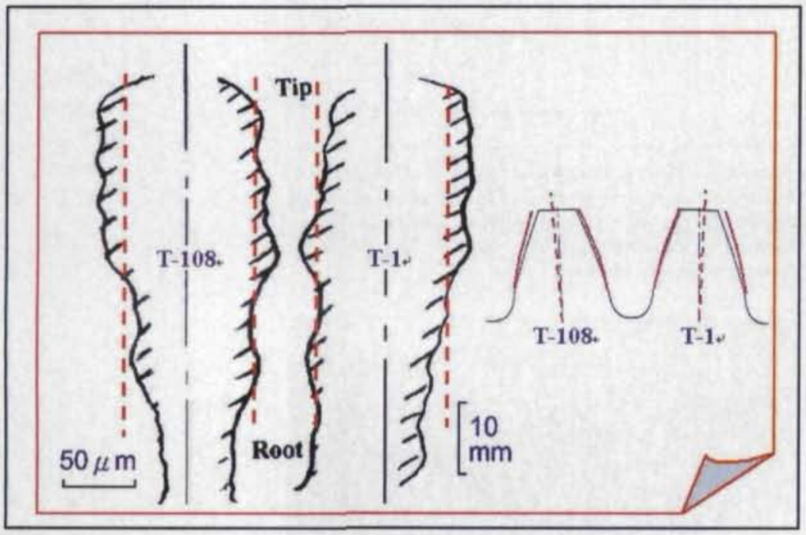

Figure 7—Tooth profile after induction hardening of tooth flank and root of gear shown in Figure 5.

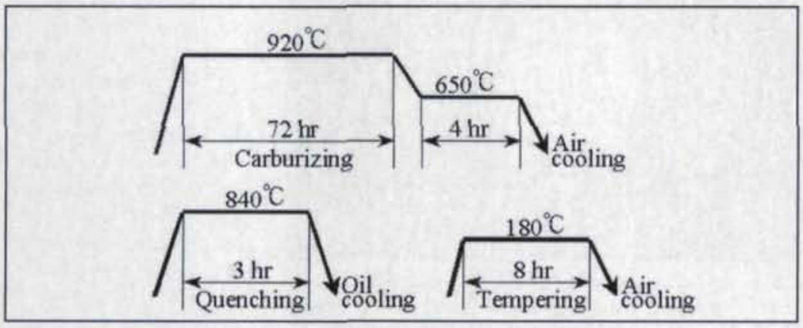

Figure 8—Carburizing process of conventional furnace, with maximum gear diameter of 1.3 m.

Figures 15 and 16 show the macrostructure and hardness distribution of a true-sized test piece from the load shown on Figure 11, which was carburized with a new 2.5 m furnace. Since the intermediate cooling occurs inside the carburizing furnace and there is nitrogen gas protection at less than 750°C, the surface of workpieces will not oxidize or decarburize; so the near-surface hardness is better than it would be if carburized via a 1.3 m furnace. Figure 17 shows the microstructure of this test piece; it is fully martensitic.

The distortion of carburized gears is a problem of great concern. According to our experience, the lower side of the gear, which touches the oil first, will shrink and that side's diameter will be smaller than the upper side's and, therefore, the gear will be a little bit conical. Consequently, the lead will change drastically. Figures 18 and 19 show the profile and lead of the gear shown in Figure 11 before and after heat treatment.

Figure 20 shows one example of load arrangement; there are 20 gears in one load. After heat treatment, we measured the geometric accuracy and hardness of every gear. In order to decrease the distortion of gears, the arrangement of workpieces during heat treatment is very important. We put plates under and above the gears to decrease their distortion. For small or ring-type gears, we overlap gears, as Figure 20 shows. For bigger gears, we have to separate them by a charging jig, as Figure 11 shows. The jig between gears will reduce the conical distortion from quenching. Figures 21 and 22 are the results of two loads arranged as shown in Figure 20 with the same heat treatment conditions. Figure 21 shows the results of normal quenching, and Figure 22 shows the results of turning the load when quenching in the oil. The latter has better geometric accuracy and more homogeneous hardness.

Performance of Carburized Gears

The performance of carburized or induction hardened gears used in a sugar plant is shown in

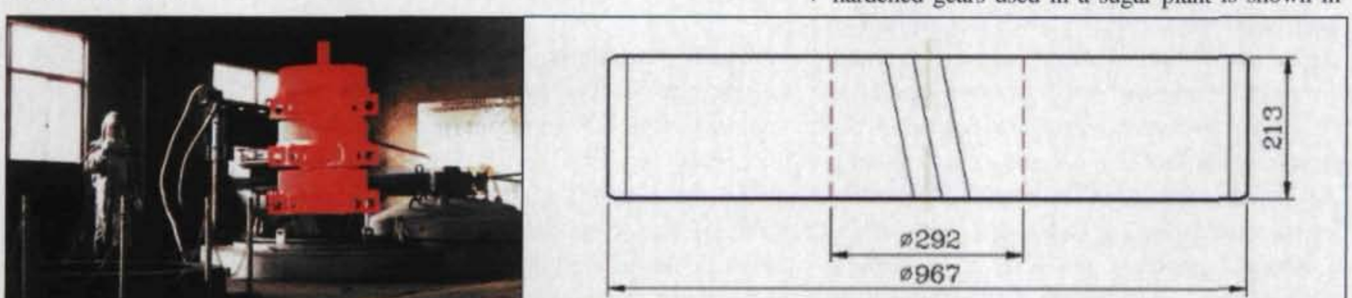

Figure 9—Just carburized gears are removed from conventional furnace before quenching. Each gear has 73 teeth, each one 213 mm long, a module of 12, an outside diameter of 967 mm and is made of SCM420H, a JIS material specification. Hardness of carburized teeth is HRC 58~59, case depth is 3.5 mm.

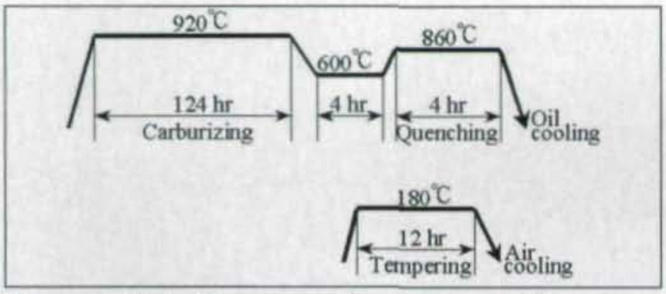

Figure 10—Carburizing process of a new furnace, with maximum gear diameter of 2.5 m.

Figure 11—Just carburized gears are removed from a new furnace before quenching. Each gear has 78 teeth, each one 407 mm long, a module of 20, an outside diameter of 1,638 mm and is made of SCM420H, a JIS material specification. Hardness of carburized teeth is HRC 58~60, case depth is 5.5 mm.

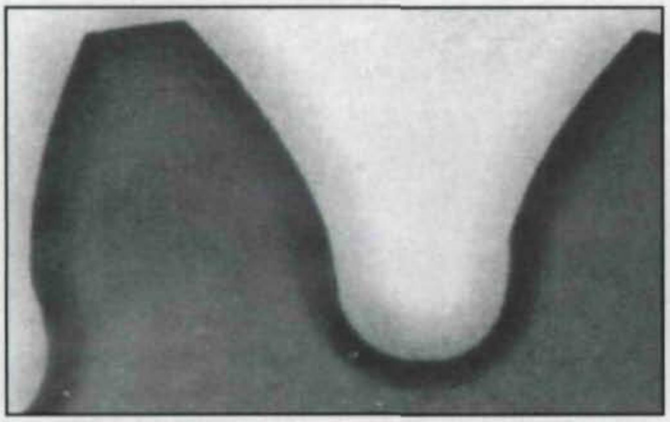

Figure 12—Macrostructure of gear test piece carburized with the gears shown in Figure 9. The test piece has five teeth, a module of 12 and is made of SCM420H, a JIS material specification.

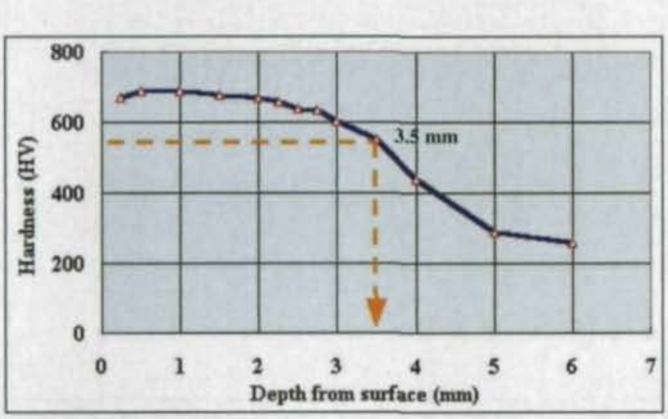

Figure 13—Hardness profile curve of gear test piece shown in Figure 12. Case depth of test piece is 3.5 mm.

Figure 14—Microstructure of carburized layer of gear test piece shown in Figure 12.

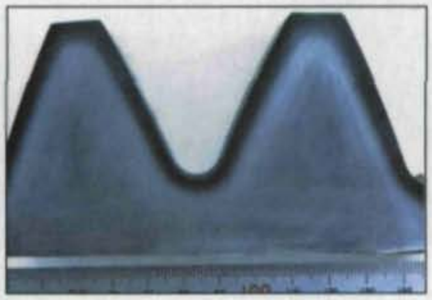

Figure 15—Macrostructure of gear test piece carburized with the gears shown in Figure 11. The test piece has 5 teeth, a module of 20 and is made of SCM420H, a JIS material specification.

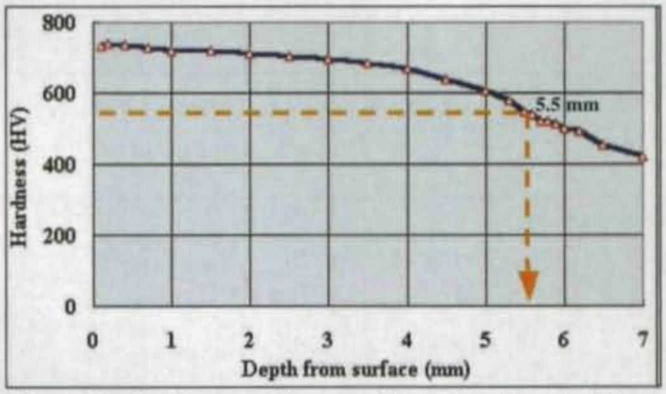

Figure 16—Hardness profile curve of test piece shown in Figure 15. Case depth of test piece is 5.5 mm.

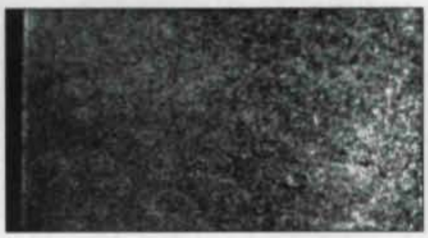

Figure 17—Microstructure of carburized layer of gear test piece shown in Figure 15.

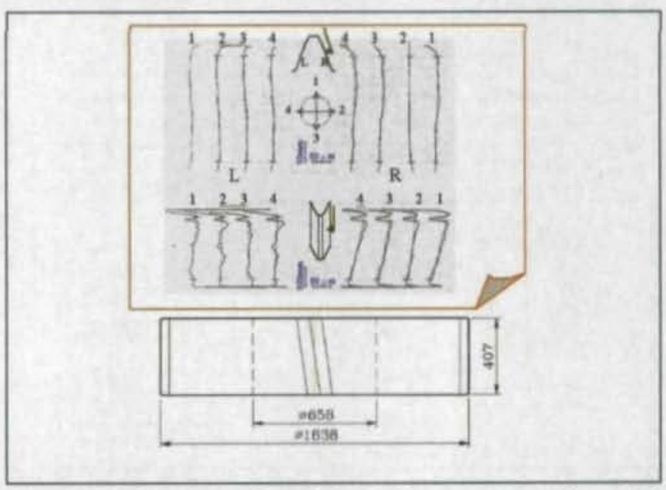

Figure 18—Tooth profile and lead of a gear from Figure 11 before carburizing.

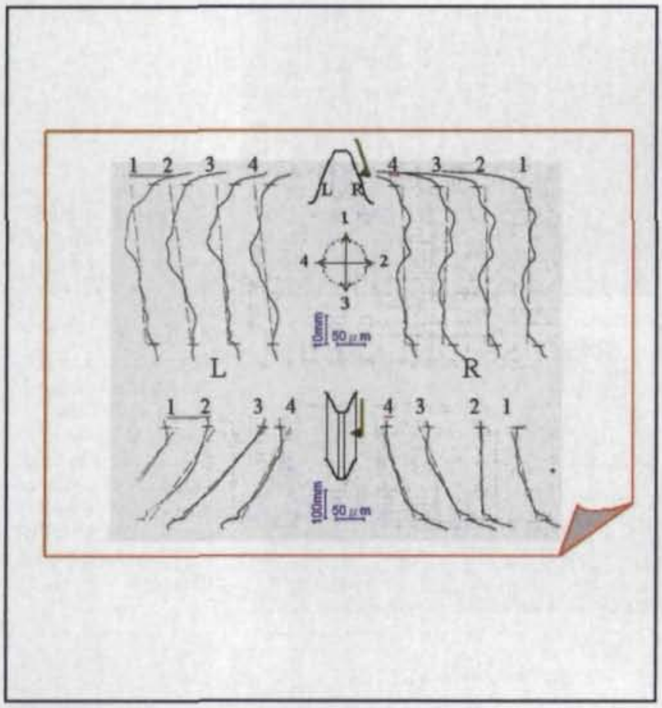

Figure 19—Tooth profile and lead of the same gear from Figure 18 after carburizing in a new process furnace.

Figure 20—Arrangement of gears before carburizing in a new process furnace. Each load consists of 20 gears. Each gear has 107 teeth, each one 160 mm long, a module of 9, an outside diameter of 980 mm and is made of 17CrNiMo6, a DIN material specification. Case depth of gears is 2.8 mm.

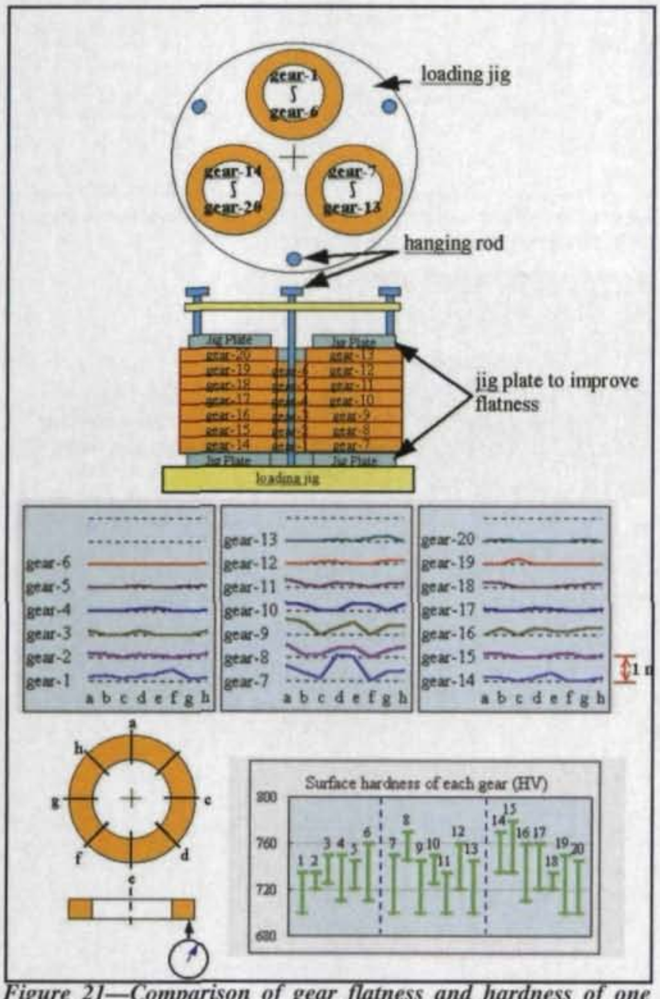

Figure 21—Comparison of gear flatness and hardness of one load of gears arranged as shown in Figure 20 and quenched normally.

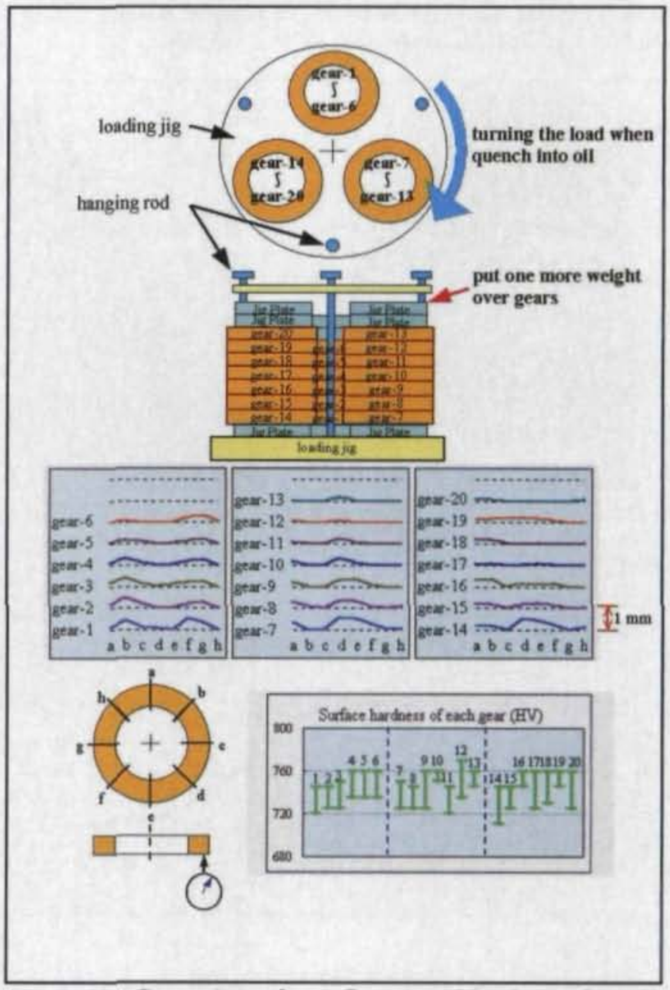

Figure 22—Comparison of gear flatness and hardness of another load of gears arranged as shown in Figure 20 and turned while quenching in oil.

Figures 23 and 24. Figure 23 shows an open gear with normalization and a pinion with quenching and tempering. They have operated for three milling seasons, and the gear tooth surface is already pitting because the surface hardness is too low. Figure 24 shows an open gear with induction hardening and a pinion with carburizing. They also were operated for three milling seasons. Since the hardness was raised for both gear and pinion, the surface is in very good condition and the gear and pinion's lives can be longer.

Conclusion

Induction-hardened gears have less lead and profile distortion compared with carburized ones, but they have less contact and bending strength. The induction hardening of big gears requires special induction coils and more operators. Of the two types of induction hardening, tooth root hardening results in more bending strength than tooth flank hardening, but the former requires more advanced technology.

Carburized gears have higher tooth surface hardness than induction-hardened gears. Also, the hardness distribution and microstructure of carburized gears are more homogeneous than they are in induction-hardened ones. Therefore, carburized gears have higher contact strength and bending strength compared with induction-hardened gears.

The distortion of carburized gears is bigger than that of induction-hardened gears. When the diameter of a gear becomes bigger, it is necessary to increase the gear's case depth to compensate for the bigger distortion. This will increase the heat-treatment time, as well as the grinding time after heat treatment. We have reduced the distortion of gears by better arranging workpieces in a load and turning the workpieces during quenching. We will continue to reduce distortion through further testing and data collection. ○

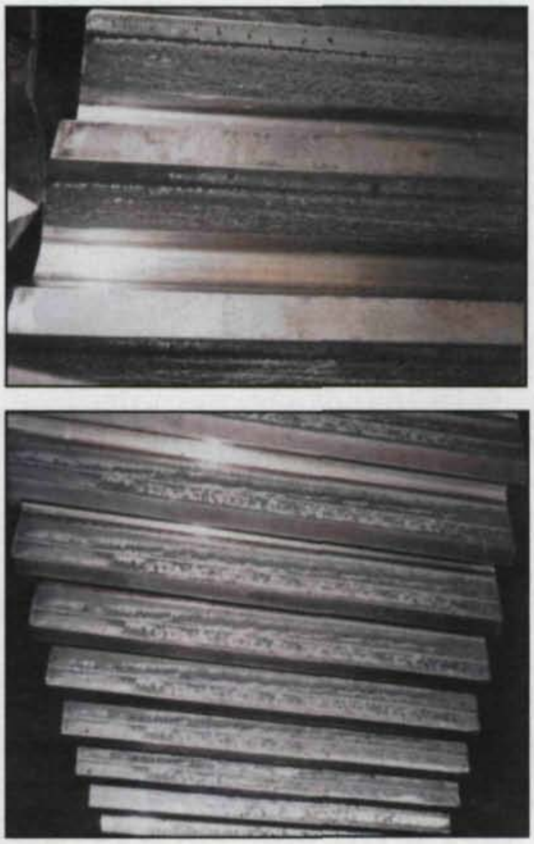

Figure 23—Open gear and pinion used in a sugar plant and made by another gear manufacturer, after three milling seasons in operation. The pinion (upper) has 22 teeth, each one 710 mm long, a module of 40, an outside diameter of 982 mm and is made of quenched and tempered SCM440, a JIS material specification. The gear (lower) has 95 teeth, each one 700 mm long, a module of 40, an outside diameter of 3,858 mm and is made of an unknown normalized material.

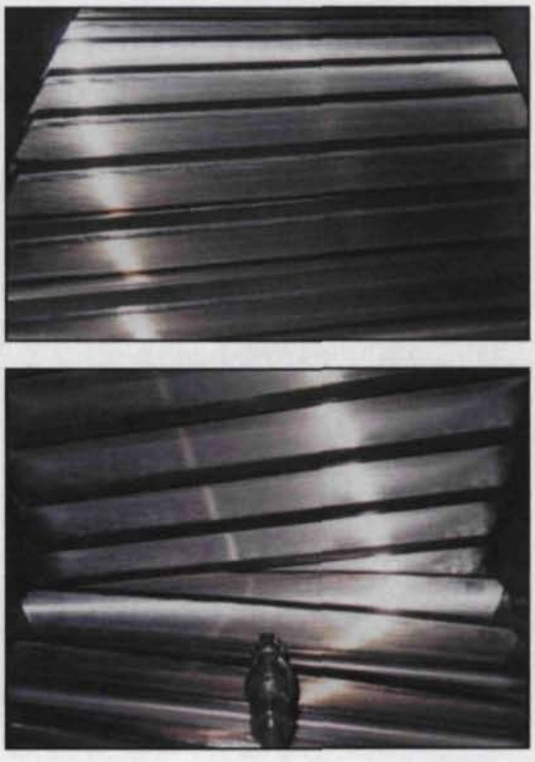

Figure 24—Open gear and pinion with the same dimensions as in Figure 23, used in the same sugar plant and made by Formosa Heavy Industries, after three milling seasons in operation. The pinion (upper) is made of SCM420H, a JIS material specification, carburized to HRC 57~59, with case depth of 4.5 mm. The gear (lower) is made of SCM440, a JIS material specification, tooth flank and root induction hardened to HRC 52~55.