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Shot Peening and the Dynamic Root Strength of Gears

The effect of shot peening on the dynamic root strength of gears treated with different parameters in different heat treatment methods

WITH MORE than 55 years of experience, FerroECOBlast® Europe, based in Dolenjske Toplice, Slovenia, is one of the global leaders in the field of surface treatment technologies. What makes us stand out from the crowd is our dedication to research and development. The following study, performed by our R&D department, in collaboration with the IMT—The Institute of Metals and Technology from Slovenia—explores the effect of shot peening on the dynamic root strength of gears treated with different parameters in different heat treatment methods.

Gears are commonly exposed to high loads. We therefore decided to choose a gear as the test sample for this particular study. The sample gears were made of standard structural steel typically used in the manufacturing of gears 18CrNiMo7 and, following mechanical treatment, underwent further processing using the three most commonly used heat treatment methods for such parts: cementation (C), nitriding (N) and carbonitriding (NC). After the heat treatment, the gears went through a shot peening process. We opted for a cold and "hot" shot peening process, the latter at an elevated temperature. The purpose of "hot" shot peening is to close the micro-cracks on the surface as much as possible and achieve better tooth micro-hardness as deep into the surface as possible. Two materials were used in the process: S110 and S330. After the basic shot peening, certain samples underwent re-peening using a finer material—Z150 ceramic beads. After the processes were completed, a metallographic analysis of the gears was conducted to measure the tooth's micro hardness and its permanent dynamic strength at two different load levels.

Shot Peening Process

The following abrasives were selected for the shot peening: Steel shot S110, Steel shot S330, and Ceramic shot Z150. The latter was used for the re-peening. By adjusting the angle of the nozzle relative to the gear, we obtained the best possible balanced intensity for the root and top land of the tooth. The process at elevated temperatures (HT) was also carried out on cemented gears, at 180˚C, and nitrided gears, at 320˚C. Carbonitrided gears, however, were not processed at elevated temperatures because this would have neutralized the effect of the preceding heat treatment.

Intensity of Shot Peening

We decided to select different shot peening intensities for different abrasives and did our best to adjust the intensity of the tooth and root of the gear as much as possible. The results of intensity for cold and hot shot peening process have been the same. Table below shows intensity value for each part of the gear with the different abrasive.

Intensity of shot peening with different abrasives

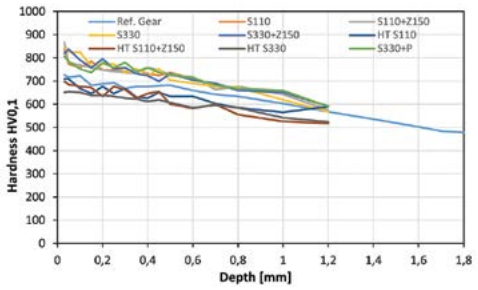
Abrasive	S110		S230		Z150	
Part of gear	Tooth	Root	Tooth	Root	Tooth	Root
Intensity	.007A	.007A	.017A	.014A	.011N	.011N

Testing and Measurements

Dynamic strength testing was performed on a dedicated machine where a gear tooth was put under two different alternating load levels. The load frequency was 15 Hz, while the forces varied: 34 kN in the first run, 40 kN in the second one.

Tooth clamping and loads during testing

After the shot peening, tooth micro-hardness measurements were conducted for each heat treatment and shot peening method combination. This helped identify the effect of shot peening on the tooth's depth from the surface and the effect of the "hot" shot peening. Also identified was the effect of the re-peening using a finer material.



Hardness distribution for cemented gears, with depths (HT – hot peening)

The results have shown the conventional shot peening treatment to increase material hardness by approx. 80–100 HV relative to the reference gear. This difference decreases as the distance from the surface increases. Measured from the surface of the material, the depth of the effect is 1–1.2 mm. "Hot" shot peening, on the other hand, results in hardness reduction by approximately 50 HV.

In the case of carbonitrided gears, shot peening increases material hardness by approximately 100 HV and that this effect decreases as distance from the tooth surface is increased. The effect of the process penetrates up to some 0.3 mm deep in the material.

For the nitrated gears, the same pattern of increasing hardness is detected. The effect of shot peening process penetrates only 0.25 mm deep into the gear tooth.

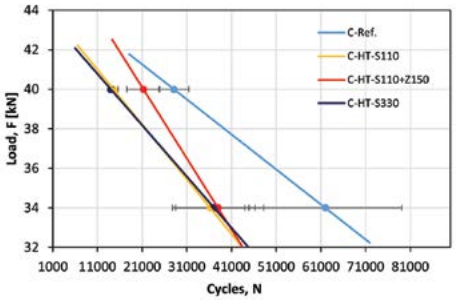
Dynamic Tooth Root Strength Testing

Cemented gears

The impact of the cold shot peening process on the dynamic root strength of cemented gears is shown in the next graph.

As can be observed in the graph, all shot peening methods except for the S110+Z150 combination result in a 10–50% deterioration in the dynamic root strength of the cemented gear. In the case of the S110+Z150 shot peening, too, the root strength at a higher load level has decreased compared to the cemented gear used for reference but, on the other hand, this treatment indicates a significantly improved resistance at lower load levels, where the teeth can withstand >300,000 load cycles without breakage.

In the case of "hot" shot peening, all three operations result in a 30–50% deterioration in the dynamic root strength of cemented gears (next graph), with "hot" shot peening using a combination of steel and ceramic beads (HT-S110+Z150) again being the closest to the reference cemented gear.



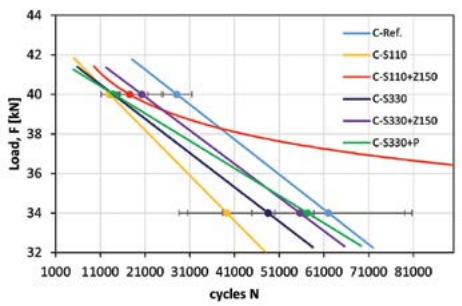
The effect of "hot" shot peening on the dynamic root strength of cemented gears

Carbonitrided gears

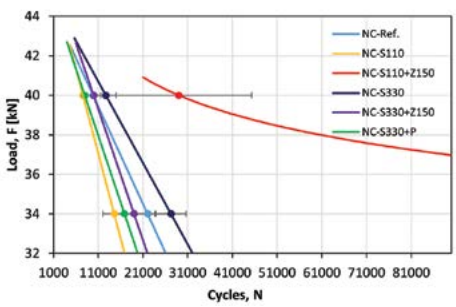
In the case of carbonitrided gears, the shot peening operations with S330 and S110+Z150 show root strength improvement, with the combination of steel and ceramic beads S110+Z150 in particular. Shot peening with S110+Z150 yields a severalfold improvement in the dynamic root strength at both /stress/ load/ levels, whereas with S330, the improvement stands at around 30% (next graph).

Nitrided gears

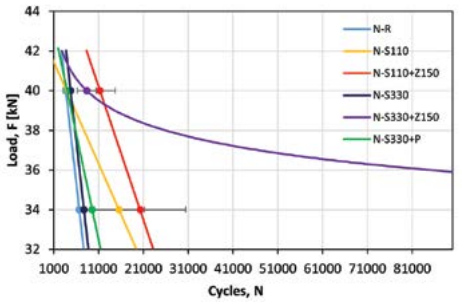
In the case of nitrided gears, all cold shot peening treatments have a positive impact on the dynamic root strength. The greatest impact was observed in treatments using a combination of steel and ceramic beads (S110+Z150 and S330+Z150), where the latter combination in particular has substantially improved the dynamic root strength at lower loads. "Hot" shot peening, too, has resulted in improved dynamic root strength of nitrided gears, mainly at lower load levels. The improvement ranges from 30–40% to more than a fivefold increase. The most notable improvement was again



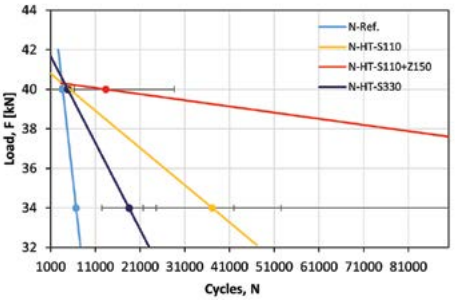
The effect of cold shot peening on the dynamic root strength of cemented gears



The effect of cold shot peening on the dynamic root strength of carbonitrided gears



The effect of cold shot peening on the dynamic root strength of nitrided gears



The effect of "hot" shot peening on the dynamic root strength of nitrided gears

achieved using the combination of steel and ceramic beads HT-S110+Z150.

Conclusion

- Shot peening treatment increases the hardness of the surface layer of gears, which holds true for all the three heat treatment methods. The highest hardness measurements have been observed in gears that underwent the S330 and S330+Z150 processes, followed by S110 and S110+Z150. In the case of cemented gears, "hot" shot peening reduces the gears' surface hardness; in nitrated gears, however, it does increase the surface hardness, but to a lesser extent than with cold shot peening.
- A comparison of the gears' dynamic root strength reveals that the highest strength is observed in cemented gears, followed by carbonitrided gears, whereas nitrided gears achieve a mere one-tenth of the dynamic strength of cemented gears. On the other hand, with cemented gears, all subsequent cold shot peening treatments, with the exception of S110+Z150, result in up to a 50% deterioration in dynamic root strength. The S110+Z150 treatment, however, has been shown to provide a substantially improved root strength at lower load levels in particular, as the teeth can withstand more than 300,000 load cycles without breakage. With "hot" shot peening, the dynamic root strength has been shown to decrease as much as twofold.
- In the case of carbonitrided gears, the S110+Z150 and S330 shot peening processes resulted in improved root strength, particularly when using a combination of steel and ceramic beads, where a severalfold improvement has been observed. Other shot peening operations had a negative impact on the gears' dynamic root strength, which decreased by up to 35%.
- In contrast, all the shot peening operations, both cold and hot, on nitrided gears yielded a substantial improvement in the gears' dynamic root strength. Again, the greatest impact can be observed in the treatment with steel beads, followed by shot peening with ceramic beads S110+Z150 and S330+Z150.
- Based on the results, it can be concluded that the best choice of treatment is a combination of cold shot peening using steel and ceramic beads (S110+Z150), which, regardless of the thermochemical treatment, results in improved dynamic root strength of gears. On the other hand, the shot peening process has the greatest effect on improving the root strength in nitrided gears, whereas in the case of cemented and carbonitrided gears the effect is largely negative. This goes to show that the thinner and harder the surface layer is after heat or thermochemical treatment, the more positive effect is achieved with the shot peening process.

One of FerroECOBlast®'s many automatic shot peening machines