POLISH ACADEMY OF SCIENCES - COMMITTEE OF MATERIALS SCIENCE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY

Conference Proceedings

12th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

Intensive Quenching – Carburizing Processes

M. Przyłęcka[a], W. Gęstwa[a], N.I. Kobasko[b], G.E. Totten[c], M.A. Aronov[b], J. Powell[b]

[a] Poznań University of Technology, Poznań, Poland

[b] IQ Technologies Inc., Akron, OH,USA

[c] G.E. Totten & Associates, Inc., Stony Point, NY,USA

Various intensive quenching (IQ) processes have been reported since the 1920's. Recently, many interesting applications requiring high surface compressive stresses. This paper provides a brief overview of IQ and describes its application to significant reduce the required diffusion times of carburizing processes.

1. INTRODUCTION

Every metallurgist has been trained that increasing cooling rates, especially in the martensitic transformation region, leads to increasing cracking potential [1]. However, since the 1920's, there have been various, often little-known industrial heat treating processes which have been designated as intense, intensive, rapid, drastic, severe, or extreme quenching or shell-hardening methods [2-8]. The essence of these methods is to harden less hardenable steels using very fast cooling rates in order to impart high compressive stresses and improved fatigue properties to the quenched component [8].

In 1964, Kobasko published the first of an extensive series of papers in which he used the term "Intensive Quenching" and showed experimental data which provided numerical evidence that showed that although it is true that increasing cooling rates result in increasing propensity for cracking as historically recognized, there does exist a critical cooling rate above which cracking propensity decreases as shown in Figure 1 [9]. Computer simulations were later used to validate and to develop design criteria for optimal conditions for conducting intensive quenching processes [10,11]. Subsequently, various industrial intensive quenching processes were developed and patented by Kobasko[12,13].

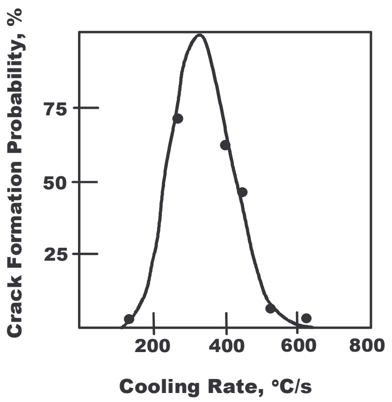

Figure 1 - Effect of Cooling Rate on the Probability of Cracking

It is important to note that the term "Intensive Quenching" does not simply mean fast quenching or quenching at an arbitrarily fast cooling rate. Instead, various reasonably descriptive and specific criteria have been published defining the conditions for intensive quenching. These include:

- Those quenching conditions that yield *maximum* surface compressive stresses [14].
- Mei has reports that the agitation rate should be sufficient to provide a Grossman Quench Severity value of > 6.0 [15].
- The Biot number criterion for maximum surface compressive stresses: $Bi \rightarrow \infty$ [16].
- For high surface compressive stresses to occur on a part being quenched, it is sufficient to meet the following condition: $0.8 \leq K \leq 1$. (Kn is the Kondratyev number.) [16]

In this paper, the mechanism of intensive quenching which provides maximum surface compressive stresses will be discussed. This will be followed by a summary description of the successful use if an IQ process to significantly reduce carburizing diffusion times while simultaneously providing improved mechanical properties.

2. DISCUSSION

2.1 Mechanism of Uniform Maximum Surface Compressive Stress Formation

Consider a steel part with a varying thickness as shown in Figure 2. During conventional quenching, martensite forms first in the thinner section of the part since this section cools faster and reaches the martensite range earlier than the thicker one (Figure 2a). The martensite specific volume is greater than the specific volume of the remaining austenite. Therefore, the thin section expands while the thick section of the part continues contracting due to cooling until it too becomes martensite. This creates stresses resulting in the distortion and possible part cracking.

Now imagine that the same steel part is cooled very rapidly and uniformly. In this instance, the martensite forms simultaneously over the entire part surface creating a hardened "shell" (Figure 2b). This uniform, hardened shell creates high compressive stresses resulting in lower distortion and lower probability of cracking.

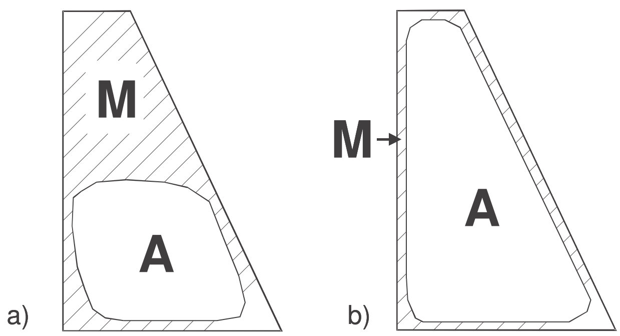

Figure 2 Martensite Formation During Drenching
a) Conventional quenching, b) Intensive quenching

A simplified surface stress formation mechanism can be illustrated by assuming that the part consists of only two sections: a "surface layer" and a "core." Now assume that the part's "surface layer" consists of a set of "segments" joined together by "springs" to form an elastic "ring" (Figure 3). When the entire steel part is heated above Ac_3 temperature before quenching there is no tension in the "springs" and there are no stresses between the "segments" (σ=0, see Figure 3a). During quenching, the surface layer cools rapidly resulting in the contraction of the "elements." To compensate for the contraction of the segments in the surface layer during cooling, the "springs" expand simulating the development of tangential (hoop) tensile thermal stresses (see Figure 3b).

When the surface layer reaches the martensite formation start temperature, Ms, the austenite in the surface "segments" transforms into martensite (see Figure 3c). The martensite specific volume is greater than that of the austenite. This results in the expansion (swelling) of the surface layer "segments", causing the "springs" to contract. The contraction of the springs illustrates the development of surface compressive hoop stresses. It is important to note that during intensive quenching, the part surface layer reaches the martensite start temperature M_s so quickly that the part core is still very hot (practically at the initial austenitizing temperature). (This is in contrast to conventional quenching, for example marquenching, when the part core temperature may be just above the M_s temperature at this period of time.)

While the martensitic structure is forming in the part surface layer, the part's austenitic core continues to cool down to the M_s temperature, shrinking in size as it cools (Figure 3d). This core thermal contraction is eesignated as "pre-phase transformation shrinkage." As the core shrinks, the strong martensitic shell maintains the part's initial size with low distortion – almost as though a "die" has been built on the outer shell of the part. The shrinking (cooling) austenitic core draws the martensitic surface shell toward the part center increasing the surface hoop compressive stresses (with the "springs" between the surface layer "segments" contracting). Note that in a real quench the material does not "break" between the shrinking austenitic core and the fixed martensitic "shell" (as shown on Figure 3d). This is because the hot austenite is in a "super-plastic" state; when stresses between the "surface" and "core" sections of the part exceed the austenite yield strength, the austenite deforms to maintain part integrity within the shell.

If intensive quenching continues further, then within a short time (in a matter of seconds), the martensite starts forming in the part "core," resulting in the core swelling (see Figure 3e). The expanded part core pushes the part surface layer back from the part center resulting in diminution, but not elimination of the high surface compressive stresses. (Put another way, the distance between the surface layer "segments" increase, resulting in the expansion of the "springs" and the lowering of the compression in the surface shell). The surface residual stresses are still compressive even in a through hardened part because the size of the expanded, martensitic core is actually smaller than the size of the initial, hot austenitic core. In other words, the steel's *pre-phase transformation shrinkage* (of the cooling austenitic core) offsets the following phase transformation *expansion* in the final, martensitic core.

At some point in time, the surface compressive stresses reach their maximum value just before martensite starts forming in the core. The key element of the IQ process is to "interrupt" the rapid, uniform cooling of the hardened "shell" when compressive stresses in the part's surface are at their maximum. The "interruption" is done by simply removing the part from the intensive quench. As the cooling rate of the part "shell" slows, the part "core" will also begin cooling more slowly and the martensite phase transformation advance may slow or cease entirely if the part is thick enough (over approximately one inch). If the martensite formation ceases, the remaining austenite in the core transforms into intermediate phases, such as bainite, ferrite, pearlite, etc. (See Figure 3f). Since this mixed "core" structure has less specific volume than a "pure" martensite core (as discussed above), the quench results in a higher level of surface residual compressive stresses compared to the through hardened version (see Figure 3e). The precise time for interruption is predicted by the IQ Technologies computer software model [14]. Usually, there is a window of several seconds to move from each stage of the intensive quench process; the thicker the part, the "bigger the window." IntensiQuench^{SM} is robust and practical for production environments .

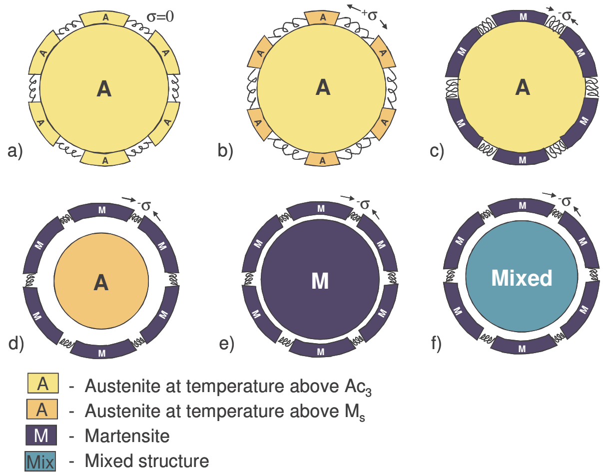

Figure 3. Surface Stress Conditions During Intensive Quenching

2.2 Shortening or Elimination of a Carburizing Cycle

Shortening or elimination of the carburization cycle can be obtained using the intensive quenching process, with the same or better hardness profile.

In the case It used carburizing processes and hardening in tradition of quenching medium (distilled water, oil and polymer water solution), We will obtained the high harnesses on section of elements, which long time of carburizing processes. These results obtained in the case of hardened carburized elements created with 20H (5120) steel (Figure 4).

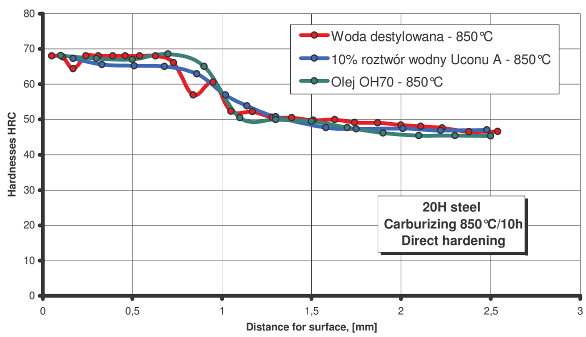

Figure 4. Hardness of 20H (5120) steel of carburized and direct hardening.

It used the IQ method can shortening or elimination of the carburization cycle, as It presentation Figure 5.

Figure 5 shows the hardness distribution throughout 8617 bearing cage with wall thickness of 4mm and case depth of 1.2-1.5 mm. Bearing cages that were carburized for only 50% of a standard carburization depth and intensively quenched have a better hardness profile than the same bearing cages that were carburized to 100% of the specification depth and quenched in oil per the standard production practices.

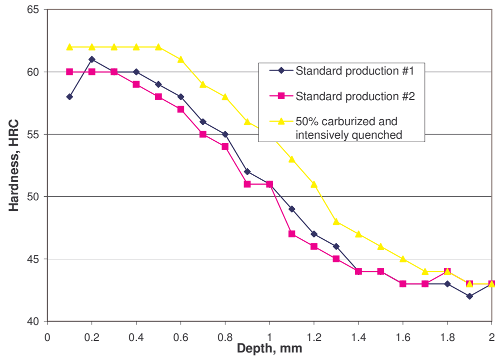

Figure 5. Hardness distribution throughout 8617 bearing cage with wall thickness of 4 mm and case depth of 1.2-1.5 mm

Figure 6 shows the hardness distribution throughout 4137 forged "shoe" (bellow the carburized case) of 110x116mm and case depth of 1.5-2.0 mm. After intensive quenching, the hardness distribution shows that there is no need to carburize this part because the process gives sufficient hardness depth with the same alloy.

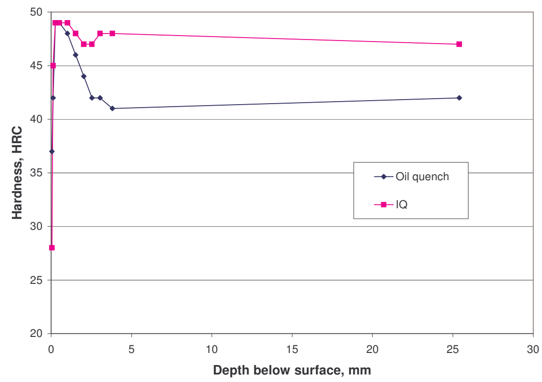

Figure 6. Hardness distribution throughout 4137 forged "shoe" cross section of 110x116 mm and case depth of 1.5-2.0 mm

3. CONCLUSIONS

In this paper, a brief overview of the intensive quenching process which includes a quantitative definition of the necessary quench severity to provide maximum surface compressive stresses. A simplified mechanism to achieve a uniform hardened case that will exhibit these maximum surface compressive stresses is described. The application of an IQ process that will provide a substantially shorter carburizing cycle time or possibly to eliminate it completely was described. These results show that the implementation of IQ process design provides a great potential for decreasing energy consumption, decreasing workplace hazards such as fire and elimination of potentially toxic quench oils which are currently in common use. Taken together, these represent a potentially enormous process improvement in the heat treating industry. Work is currently in progress at the Poznan University of Technology to study and develop IQ processes for application in the heat treating industry. These results will be reported as they are completed.

REFERENCES

1. G. Beck, Mem. Etud. Sci. Rev. Metall., 1985, June, p. 269-282.
2. R.F. Kern, Heat Treating, 1986, September, p. 19-23.
3. H. Kurz, USP 1,828,325, October 20,1931.
4. R.H. Hays, J.E. Sansom and K.D. Gladden, USP 3,506,501, April 14, 1970.
5. B. Paddock, USP 3,517,676, June 30, 1970.
6. R.H. Hays, J.E. Sansom and K.D. Gladden, USP 3,589,697, June 29, 1971.
7. J.E. Sansom, USP 3,515,601, June 2, 1970.
8. R.B. Liss, C.G. Massieon and A.S. McKloskey, "The Development of Heat Treat Stresses and Their Effect on Fatique Strength of Hardened Steels", SAE Technical Paper Series, Paper Number 650517, 1965.
9. N.I. Kobasko, Metallovedenie and Termicheskaya Obrabotka Metallov, 1964, No. 2, p. 53-54.
10. N.I. Kobasko, "Chapter 10.4 - Intensive Steel Quenching Methods", in Theory and Technology of Quenching, Eds. B. Liscic, H.M. Tensi and W. Luty, 1992, Springer-Verlag, Berlin, Germany, p. 367-389.
11. B.L. Ferguson, N.I. Kobasko, M.A. Aronov, and J. Powell, in 19th Heat Treating Society Conference Proceedings, Eds. S. Midea and G. Pfaffmann, ASM International, Materials Park, OH, 1999, p. 355-362.
12. N.I. Kobasko, Steel Quenching in Liquid Media Under Pressure, 1980, Naukova Dumka, Kiev, Ukraine.
13. V.A. Lisovoy, N.I. Kobasko, M.V. Kindrachuk, and A.A. Khalatov, USSR Patent 4,176,788, 1987.
14. G.E. Totten, N.I. Kobasko, M.A. Aronov and J. Powell, "Overview of Intensive-Quenching Processes", Industrial Heating, 2002, Vol. 69, No. 4 (April), p. 31-33.
15. Mei Daming, "Intensive Quenching method for Preventing Quench Cracking", Proceedings of the 7th International Congress of Heat Treatment and Technology of Surface Coating", 1990, Vol. 2, p. 62-71.
16. N.I. Kobasko, V.S. Morhunyuk, V.V. Dobrivecher, and G.E. Totten, "Intensive Quenching Creates Compressive Stresses at the Surface in Through Hardened Steel Parts", Proceedings of Heat Treatment and Surface Engineering in the Production of Automotive Components, Bangkok, Thailand, January 27-30, 2003, Published by National Metals and Materials Technology Center (MTEC), Bangkok, Thailand.