Assurance of Quality Improvement for Tool Steel by Cryo-processing

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Abstracts

Cryo-processing, a supplementary process to conventional heat treatment, involves freezing of materials at cryogenic temperatures to enhance the mechanical and physical properties of materials. This paper deals with improvement of properties of the tool steel by cryogenic treatment and its greater life span in an industrial application. After the Second World War cryogenic technology were abandoned until the seventies when aerospace industry took up this technology again and the treatment started to be developed as a new industrial process. Today cryogenic treatment would be regarded as one of the most important processes in the field of industries, and it is the ultra modern type of processing to make the metals more resistant to wear and more durable. The use of this treatment is extremely environmentally friendly and absolutely produces no waste during the process. The properties of the cryogenic treated tool steel are generally gained due to the conversion of austenite to martensite. Proper heat treating can transform 85% of the retained austenite to martensite and the cryogenic treatment only transforms an addition of 8 to 15%. Present investigation is about cost and durability after and before cryogenic treatments. As it is known the most important problems faced by the industries are the wear and tear of the machine parts. This wear of the machine parts not only increases the cost of production but also the time wasted for the replacement process. Cryogenic technique gives assurance for solve these problem. These ultra-cold temperatures, below -310°F, will greatly increase the strength and wear life of all types of vehicle components, castings and cutting tools. In addition, other benefits include reduced maintenance, repairs and replacement of tools and components, reduced vibrations, rapid and more uniform heat dissipation, and improved conductivity.

Key words: Cryogenic Treatment; Tool Steel; Martensite; Austenite.

1. Introduction

Many companies are looking forward for a secret that can help them keep a step ahead of the competition. That secret is cryogenic technology. Some experiments of cryogenic treatment on steel started at the beginning of 20th century and many investigations are going forward [1-4]. This is especially important for progressive dies, where cumulative tolerances are critical. Subzero treatments have as their ultimate goal an increase in wear resistance, improve bending fatigue life, and minimize residual stress. Stress is the enemy of the steel, if it is not imparted in a uniform manner. Residual stresses exist in parts from the original steel forming or forging operation, and additionally as a result of the many different machining operations to finish the part. Residual stresses are uneven and located variously throughout the structure. Austenite (a soft form of iron) is a solid solution of carbon and iron that is retained during the quenching phase of metal production. This untransformed austenite is brittle and lacks dimentional stability, which allows the metal to break more easily under loads. To eliminate austenite, the quenching temperature has to be lowered. When the metal is cryogenically treated, austenite structure is transformed slowly into a highly organized grain structure called martensite, a body centered tetragonal crystal structure. Martensite is a finer and harder material that brings high wear resistant and better dimensional stability that is very desirable in carbon steels. There is always a certain amount of martensite phase present, but prior to cryo the ratio of strong martensite to weak austenite is less than favorable. Fully martensite steel results a much improved part or tool with no cracking, warping, or any other cryogenically-imposed-defect. Gears [5], engine & transmissions [6], and disc brakes run cooler [7], HSS cutting tools and dies [8] are among the most frequently recommended applications for cryogenic treatment.

Cryogenic treatment of tool steel gives many advantages, which are described as: (i) Increases abrasive wear resistance, (ii) Decreases residual stresses, (iii) Increases tensile strength, toughness and stability, (iv) Creates a denser molecular structure, (v) Creates a denser molecular structure, (vi) Decreases brittleness, (vii) The result is a larger contact surface area that reduces friction, heat and wear, (viii) Transforms almost all soft retained austenite to hard martensite, (ix) Forms micro fine carbide fillers to enhance large carbide structures, (x) Increases durability or wear life, (xi) used for coated as well as uncoated tool steel, (xii) a better conductor giving the metal better electrical conductivity.

2. Experimental Procedure

These ultra cold temperatures are achieved using computer controls, a well-insulated treatment chamber. Liquid nitrogen (LN_2) is used as the cryogen in this process. Liquid nitrogen is converted to a gas before it enters the chamber. The liquid form is the product of air separation, compression and liquefaction. The tool parts to be processed are placed in a processor. It is a computer controlled process the system is controlled with proven cooling curves programmed to the computer. Any other desired cooling curves may be easily programmed into the processor. Computer controlled processing ensures accurate tempering cycles and assuring that the dangers of cracking from too rapid cooling/heating are eliminated. They are gradually cooled with nitrogen gas to -320ºF. That temperature is maintained for at least eight hours. The length of time varies by material and desired results. After the cooling cycle is complete, the item is slowly warmed back to room temperature. Then the object is heat with temperatures of 100ºF to 400ºF, depending on the desired final product and the item is gradually returned to room temperature. The complete process takes a minimum of 24 hours to a maximum of 7 days. The entire cycle of cooling and tempering can be known from Figure-1.

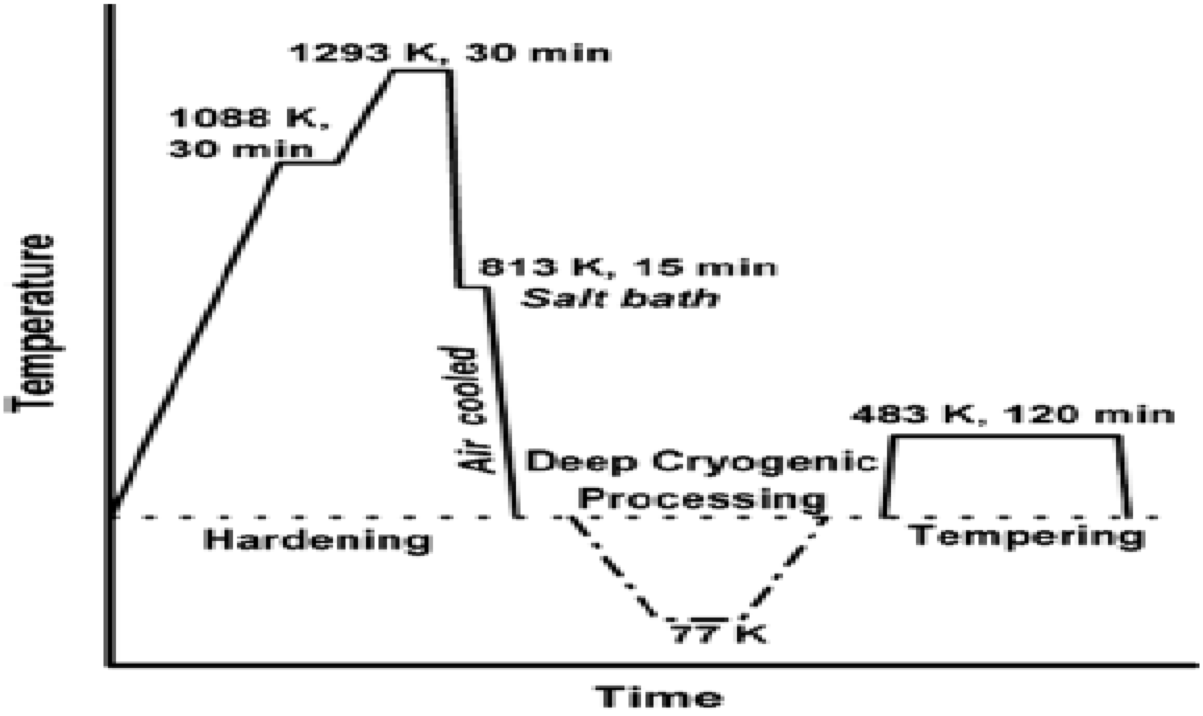

Fig 1. Total heat treatment process indicating cry-processing within it.

3. Results and Discussion

Based on before and after analysis, we know that cryogenic treatment provides for some documented transformations in metals (crankshaft parts). In first treatment in heat-treated steels, it is observed that retained austenite is transformed to martensite, creating a more uniform grain structure and homogenous steel. This provides for a tougher and more durable material as the voids and weaknesses of an irregular grain/crystal structure is eliminated. When final machining, polishing, grinding or honing are done after cryogenic treatment, it leads to friction reducing qualities in metals. It is also why cryogenically treated steels show more uniform hardness than non-treated steels. In many steels, the transformation of austenite to martensite is complete when the part reaches room temperature. (I.e. other steels, however, including many tool steels, some of the softer austenite phase is retained). Subsequent cooling to a lower temperature can cause additional transformation of the soft austenite to hard martensite. However, it is possible also to transform all of the retained austenite in the steel by appropriate elevated-temperature tempering treatments that carry the added benefit of reducing the brittleness of the martensite. Transformation of retained austenite at low temperatures in tool steels generally is believed to be dependent only on temperature, not on time. Cryogenic treatments can produce not only transformation of retained austenite to martensite, but also can produce metallurgical changes within the martensite. The martensitic structure resists the plastic deformation mush better than the austenitic structure, because the carbon atoms in the martensitic lattice lock together the iron atoms more effectively than in the more open-centered cubic austenite lattice. Tempering the martensite makes it tougher and better able to resist impact than un-tempered martensite. Secondly, cryogenic treatment of high alloy steels, such as tool steel, results in the formation of very small carbide particles dispersed in the martensite structure between the larger carbide particles present in the steel. This strengthening mechanism is analogous to the fact that the concrete made of cement and large rocks is not as strong as concrete made of cement, large rocks and very small rocks i.e. Coarse sand. The small & hard carbide particles within the martensitic matrix help support the matrix and resist penetration by foreign particles in abrasion wear. The reported large improvements in tool life usually are attributed to this dispersion of carbides in conjunction with retained austenite transformation. The treatment calls for a precise temperature control during the processing, usually up to one-tenth of one degree, necessitating elaborate controls and sophisticated instrumentation. Freshly formed martensite changes its lattice parameters and the c/a ratio approaches that of the original martensite. Etta (η) carbide precipitates in the matrix of freshly formed martensite during the tempering process. This η carbide formation favors a more stable, harder, wear-resistant and tougher material. This strengthens the material without appreciably changing the hardness (macro hardness). The other major reason for the improvement is stress relief. The densification process leads to an elimination of vacancies in the lattice structure by forcing the material to come to equilibrium at -196ºC and lowering the entropy in the material. This lower entropy leads to the establishment of long range order in the material which leads to the minimization of galvanic couples in the material thus improving the corrosion resistance of materials including Stainless Steels. Besides, there is some amount of grain size refinement and grain boundary realignment occurring in the material. These two aspects lead to a tremendous improvement in the electrical and thermal conductivity of the material thus transporting the heat generated during the operation of the tool away from the source and increasing its life. In figure-2, life of the tools are compared between before-cryo-treatment and after-cryo-treatment process. Because austenite and martensite have different size crystal structures, there will be stresses built in to the crystal structure where the two co-exist. Cryogenic processing eliminates these stresses by converting most of the retained austenite to martensite. This also creates a possible problem. If there is a lot of retained austenite in a part, the part will grow due to the transformation. This is because the austenitic crystals are about 4% smaller than the martensitic crystals due to their different crystal structure. The process also promotes the precipitation of small carbide particles in tool steels and steels with proper alloying metals. A study in Rumania found the process increased the countable small carbides from 33,000 per mm to 80,000 per mm. The fine carbides act as hard areas with a low coefficient of friction in the metal that greatly adds to the wear resistance of the metals. Cryogenic processing will not in itself harden metal like quenching and tempering. It is not a substitute for heat-treating. It is an addition to heat-treating. Most alloys will not show much of a change in hardness due to cryogenic processing. The abrasion resistance of the metal and the fatigue resistance will be increased substantially. By cryo-treatment the ideal time of the machine part replacement reduces. Cryo-teated parts are equivalent to 3 times replacement of the non-cryo-treated parts. So cumulative cost is reduced, which is shown in figure-3 for different parts of crankshaft.

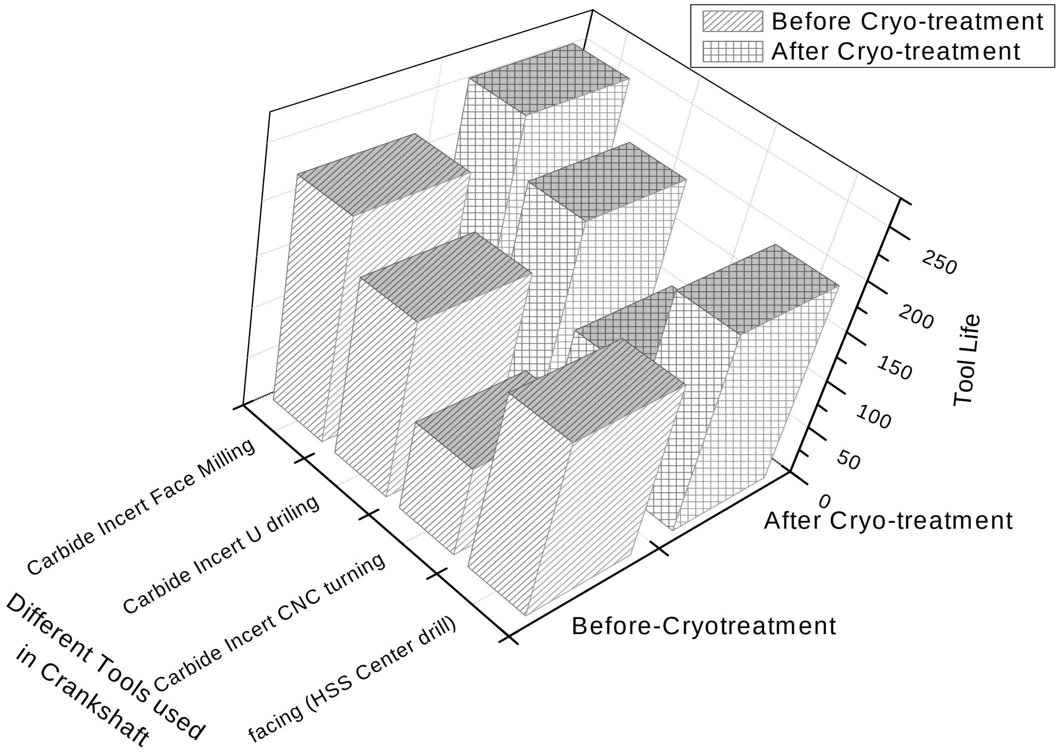

Fig 2. Comparision of tool life in between before-cryo-treated and after-cryo-treated process.

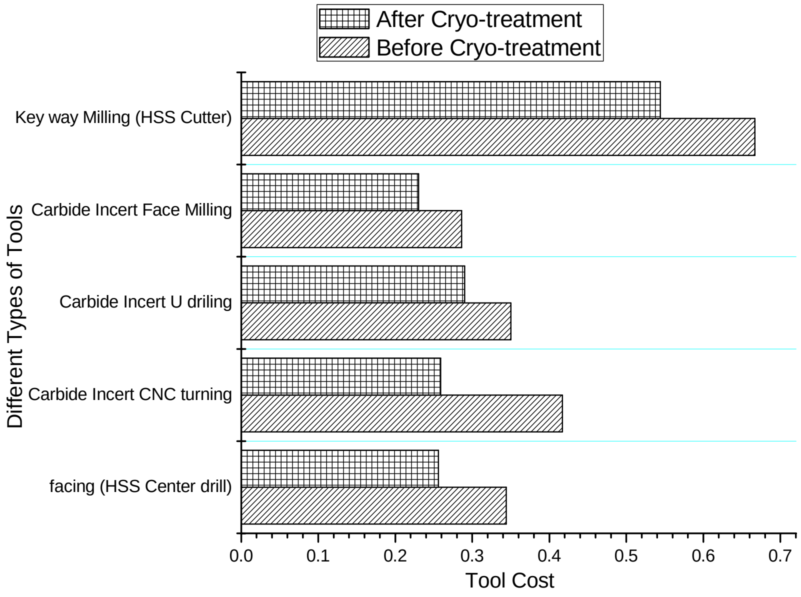

Fig 3. Comparision of cumulative cost of tool in between before-cryo-treated and after-cryo-treated process.

4. Conclusions

The future of cryogenics materials will be very exciting and dynamic. It will be driven by traditions, trends, costs, performance, legislation. Of these, the most critical issue is costs. Logical, creative and inovative ideas will have little chance of success if the economics are not positive. Cryogenics materials will be part of the dynamic future. We must not only continue to make incremental improvements in present materials but develop whole new technologies of manufacturing and processing for to achieve the highest performance in cryogenics materials field. Cryogenics-based technologies have applications in wide variety of areas as metallurgy, chemistry, power industry, medicine, rocket propulsion and space simulation, food processing.

5. References

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