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Application of Deep Cryogenic Treatment on Improving Service Life of Tools and Molds

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Abstract: In this paper, HSS bit, tap, vertical milling cutter, YT15 milling cutter, 9CrSi and Cr12 Mold materials are treated by deep cryogenic. The hardness and red hardness of materials before and after deep cryogenic are tested and contrasted. And industrial production is carried out on the part of tools and molds. The result indicates that deep cryogenic can improve the hardness and red hardness of materials to some extent. It can also improve the wear resistance of materials, which extends the service life of tools and molds. Therefore, the deep cryogenic treatment is one of stong methods to improve the service life of tools and molds.

Metal cutting is one of the mainstream processing methods in the machinery manufacturing industry. Most components with high requirements for dimensional accuracy and surface quality undergo cutting processing. The level of cutting technology (including cutting methods, cutting tools, molds, processing techniques, etc.) plays a pivotal role in processing accuracy, product quality, productivity, and production costs, especially the characteristics of the cutting tools and molds used. According to cost accounting, the cost of cutting tools and molds typically accounts for 5%-10% of the total manufacturing cost of a product. However, the indirect production costs resulting from the influence of tools and molds, such as downtime losses caused by machine shutdowns, mold maintenance hours, and the cost of treating cooling and lubricating fluids, account for a larger proportion of the manufacturing cost. Therefore, enhancing the wear resistance and stability of tool and mold materials can improve their service life to a certain extent, reduce the breakage rate, and ultimately increase cutting allowances, decrease auxiliary working hours, and reduce production costs.

As a manufacturer of coal mining machinery, our company produces a wide range of tools and molds, most of which require cutting processing. The annual cost of consuming these tools and molds amounts to hundreds of thousands of yuan. Therefore, increasing the service life of our tools and molds can effectively reduce our production and processing costs, achieve the goal of "energy conservation, emission reduction, cost reduction, and efficiency improvement," and greatly promote lean management efforts.

In recent years, the cryogenic treatment technology, as a material processing method, has continuously been applied in production practices. A large number of research results have shown that [1-5] cryogenic treatment can not only reduce the residual austenite content after quenching, improve dimensional stability, and enhance mechanical properties such as material hardness, wear resistance, and red hardness, but also extend the service life of parts to varying degrees.

This article presents an experimental study on the cryogenic treatment of externally purchased finished cutting tools and molds from our company. Through mechanical performance testing and analysis, as well as production verification, the service life of tools and molds has been effectively improved.

1. Experimental Materials and Methods

The tool materials selected for the experiment include finished W4Mo3Cr4VSi high-speed steel drills, taps, end mills, and YT15 milling inserts purchased from our factory's suppliers. The mold materials are 9CrSi and Cr12. The SLX-250 cryogenic treatment chamber with automatic temperature control is used to perform the cryogenic treatment on these materials. The process parameters are shown in Table 1. For the mold materials 9CrSi and Cr12, the cryogenic treatment is conducted after conventional quenching and tempering, followed by a low-temperature tempering at 180℃ to eliminate residual stress.

Table 1: Cryogenic Treatment Process Parameters

Material	Temperature	Cycle Times	Cooling Rate	Heating rate
W4Mo3Cr4VSi	-196℃	24h	4℃/min	10℃/min
YT15	-196℃	24h	4℃/min	10℃/min
9CrSi	-196℃	6h	4℃/min	10℃/min
Cr12	-196℃	6h	4℃/min	10℃/min

The TH300 Rockwell hardness tester was selected to measure the hardness values before and after cryogenic treatment, and a red hardness test was conducted: the tools and molds before and after cryogenic treatment were heated to 600℃ in the RJJ-15 box-type furnace, kept warm for 2 hours, and then their hardness values were measured after cooling. Finally, some of the tools and molds that underwent cryogenic treatment were tested in industrial production.

2. Experimental Results

2.1 The hardness of tools and mold materials before and after cryogenic treatment

Table 2 lists the hardness values of four materials before and after cryogenic treatment.

Table 2: The hardness values of four materials before and after cryogenic treatment

Material	Before	After	Difference
W4Mo3Cr4VSi	HRC63.6/HRC64.2	HRC64.5/HRC65.3	HRC0.9/HRC1.1
YT15	HRA90.6/HRA91.4	HRA92.4/92.8	HRA1.8/HRA1.4
9CrSi	HRC60.3/HRC59.8	HRC61.5/HRC61.3	HRC1.2/HRC1.5
Cr12	HRC61.2/HRC60.5	HRC63.8/HRC63.5	HRC2.6/HRC3.0

From the above data, it can be seen that the hardness of the materials only undergoes slight changes after cryogenic treatment, with a relatively small increase. The change in hardness is mainly due to the martensite transformation of residual austenite in the material after cryogenic treatment, along with the precipitation of ultrafine carbides. Some data and research results have proved that [6] under the same conditions (same friction coefficient, composition, structure, and environmental conditions), there exists a nonlinear positive proportional relationship between hardness and wear resistance. Therefore, cryogenic treatment can improve the wear resistance of materials to a certain extent.

2.2 The red hardness of tools and mold materials before and after cryogenic treatment

Red hardness refers to the ability of a material to resist a decrease in hardness as the temperature rises. The red hardness of a material is an important indicator of its cutting performance. The higher the red hardness, the better the material's ability to resist thermal wear during cutting. Therefore, good red hardness is significant for improving the wear resistance of materials. Table 3 lists the hardness values of the four materials after heating to 600℃ before and after cryogenic treatment.

Table 3: The hardness values of four materials before and after cryogenic treatment

Material	Before	After	decline extent	
			Before	After
W4Mo3Cr4VSi	HRC56.0/HRC55.8	HRC60.5/HRC61.2	HRC7.6/HRC8.4	HRC4.5/HRC4.1
YT15	HRA88.6/HRC88.9	HRA91.2/HRC90.4	HRA2.0/HRC2.5	HRA1.2/HRC2.4
9CrSi	HRC48.5/HRC48.2	HRC56.8/HRC57.5	HRC11.8/HRC11.6	HRC4.7/HRC3.8
Cr12	HRC50.5/HRC51.0	HRC59.2/HRC60.0	HRC10.7/HRC9.5	HRC4.6/HRC3.5

From the above data, it can be seen that the decrease amplitude of the hardness value of the material after cryogenic treatment is relatively small. Cemented carbide itself has good red hardness and the change is not significant. Mold materials 9CrSi and Cr12 after cryogenic treatment have a low content of residual austenite and stable structure, so even if the hardness value changes after secondary heating, it is not significant. This indicates that cryogenic treatment can improve the red hardness of materials.

2.3 Application examples of cryogenic treatment for tools and molds

Table 4 lists the application examples of cryogenic treatment for tools and molds. Compared with untreated ones, the service life of the treated tools and molds has been greatly improved, with an increase range of 169% to 325%, resulting in significant economic benefits. In addition, untreated cutting tools often suffer from blade burnout and edge chipping during the production and processing, while this phenomenon has been significantly improved after cryogenic treatment, effectively reducing the number of sharpening and greatly improving production efficiency. It can be seen that cryogenic treatment is one of the powerful means to improve the service life of tools and molds.

Table 4: Application examples of cryogenic treatment for tools and molds

	Material	The processed material	Service life	
			Before	After
Φ10.3Twist drill	W4Mo3Cr4VSi	Q235	697	1250
Φ12.2Twist drill	W4Mo3Cr4VSi	Q345	468	1025
Φ16.2Twist drill	W4Mo3Cr4VSi	Q235B	100	270
Φ20.2Twist drill	W4Mo3Cr4VSi	Q235B	40	130
M12Tap	W4Mo3Cr4VSi	Q235	392	890
M14Tap	W4Mo3Cr4VSi	Q345	275	470
M20Milling cutter	W4Mo3Cr4VSi	Q235B	230	510
M24Milling cutter	W4Mo3Cr4VSi	Q235B	180	330
Welded Lathe Tool	YT15	42CrMo	130	220
Punch	9CrSi	Q235	10000	25000
Punch	Cr12	08Al	1500	3500

In recent years, our company has been focusing on the industrial construction in four aspects:

production capacity, quality, efficiency, and cost. Especially in terms of cost construction, our company advocates opening up sources and cutting expenses, reducing costs and increasing efficiency, and vigorously promoting lean management. The tools and molds after cryogenic treatment have increased strength and hardness, resulting in a doubling of wear resistance. The economic benefits are not just reflected in significantly reducing the wear and tear of tools and molds and extending their service life, but also in improving work efficiency, reducing maintenance and replacement time, reducing maintenance time and costs, and reducing inventory and scrap quantities. Therefore, cryogenic treatment is undoubtedly a good method for "reducing costs and consumption, tapping potential, and increasing efficiency", which can truly save time and money, and promote the company to move towards an efficient, high-quality, low-consumption, and green machinery manufacturing industry.

In addition, coal mining machinery products have long been regarded as "large, clumsy, and awkward" in people's minds. Often, only the structural design is emphasized while ignoring the tapping of the inherent material properties. If we try to introduce the cryogenic treatment technology into the field of coal mining machinery manufacturing, and apply a simple cryogenic treatment to some key components or components with high lifespan requirements on the belt conveyor, such as expansion sleeves, coupling halves, inner and outer rings of backstops, and wedge blocks, on the basis of the existing materials and processes, it can achieve high performance and long lifespan with lower costs, which will generate significant economic benefits [7].

3. Conclusion

(1) Cryogenic treatment can improve the hardness and red hardness of materials, thus enhancing their wear resistance.

(2) After the cryogenic treatment, the service life of tools and molds has been greatly improved, with an increase range of 169% to 325%, resulting in significant economic benefits. Therefore, cryogenic treatment is one of the powerful means to improve the service life of tools and molds.

(3) Through further research and trials, we can attempt to introduce cryogenic treatment technology into the field of coal mining machinery manufacturing, achieving high performance and long lifespan with lower costs, which will generate significant economic benefits.

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