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MATERIALS FOR INJECTION MOLDING MACHINES SCREWS FOR PROCESSING OF PLASTIC MATERIALS UP TO 30% OF GLASS FIBERS PRODUCED BY POWDER METALURGY

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Abstract:

In the article there are investigated materials, which are used for production of the injection molding machine´s screws used for processing of plastic materials with content of glass fibers up to 30%. These materials are produced by the powder metallurgy – by the HIP (Hot Isostatic Pressing). Structures of materials are analysed by optical microscope and compared with conventionally produced materials. Based on literature sources there are specified conditions of further processing of materials or rather conditions which are recommended for the test of these materials nitridation.

1 Introduction

During the 20th century man developed a new, cheap and easily workable material. Plastic. Plastic materials started expanding from the interwar period. Reason of its more often use was the fast development, price and properties. Step by step plastics started to push away wood, glass and later, the metal from some application fields. Intense evolution brought also its processing technology development. Widest processing technology is injection molding where melted plastic from plastification unit is injected into the mold under high pressure. Plastic solidifies in the mold and its dimensions are fixed partially. Final product is removed from the tool. Within the scope of development of plastics, its properties were elaborated. Toughness, rigidity, resistance against different substances or elasticity as the thermoplastic elastomers were in the focus of developers. Adjustment of the material content and various kinds of bindings had different influence on the injection molding screws – sticking on the screw, its corrosion up to abrasive wear by plastic material. By this reason producers of injection molding machines had to concentrate on the development of the screws – its geometry, but also the material of the screw. And therefore, step by step they got to some basic sorts of materials which are used for different groups of plastics. Basic differentiation of these materials is following:

1. Screws for using with plastic materials without glass fibers and fillers
2. Screws for using with plastic materials with fillers and glass fibers up to 30%
3. Screws for using with plastic materials with fillers and glass fibers up to 50%
4. Screws for using with special plastics (technical, transparent, etc.)

Most used category of the screws is those for using with plastic with glass fibers up to 30%. These screws are the most universal and shows usually best corrosion resistance. Most of plastic, if the higher toughness demanded, are used with the glass fibers up to 30%. Over this line there are used materials for special purposes and their representation in

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production is considerably lower. One of the reasons is the price of material used for their production, very expensive technological processes of machining, necessity of special tools using and etc.
Very interesting is category with 30% of glass fibers. Screws for most used diameters are produced by powder metallurgy. Among such materials there are powder metallurgy steels M390 and M398 Microclean© from Austrian company named Böhler.

Plastic material category / Screw diameter	Basic plastic materials without fillers and additives	Plastic materials with fillers and additives with glass fibers up to 30%	Plastic materials with fillers and additives with glass fibers up to 50%	Special applications: Chrome Nitride	Special applications: Titan Nitride
Screws up to diameter 65 mm	Nitriding steel, nitrided	Powder metallurgical steel, hardened and tempered	Full tungsten carbide armoring	Plastic mod steel, CrN-coated	Plastic mold steel - TiN coated
Screws over diameter 65	Quenched and tempered steel with flight armoring, nitrided	Quenched and tempered steel with flight armoring, nitrided	Full tungsten carbide armoring	Quenched and tempered steel with flight armoring and CrN coating	Quenched and tempered steel with flight armoring and TiN coating

Table 1 Materials for injection molding screws [1]

2 Experimental details

Powder metallurgy stainless steels M390 and M398 belong to categories of materials which properties supersede commonly produced steels. It is by the reason that HIP method is able to produce materials which are not possible to produce by standard approach otherwise during the cool down phase there would segregate single components. These powders steels are produced at approx. 06 - 0.8 * temperature of solidus [10] and high pressure, what allows the material to join into a compact pattern but it does not allow to change a position of single components. It is necessary to pay high attention at a thermal and thermo-chemical processing of these materials to avoid enormous growth of the grain and detracting of surface layer for the components which have important assignment (for example – during nitridation there comes a combination of Nitrogen and Chrome and creation of Chrome nitrides what decreases corrosion resistance of material.)

2.1 Böhler M390 Microclean© powder metallurgy steel and its properties

Material M390 has following composition and properties:
Steel composition:
1.90 % C, 0.70 % Si, 0.30 % Mn, 20% Cr, 1% Mo, 4% V, 0.60 % W.
Material properties:
Density at 20 °C – 7.54 kg/dm3
Thermal conductivity – 16.5 W/(m.K)
Thermal expansion between 20 °C and
20 °C - 100 °C - 10.4 x 10-6 m/(m.K)
20 °C - 200 °C - 10.7 x 10-6 m/(m.K)
20 °C - 300 °C - 11.0 x 10-6 m/(m.K)
20 °C - 400 °C - 11.2 x 10-6 m/(m.K)
20 °C - 500 °C - 11.6 x 10-6 m/(m.K)

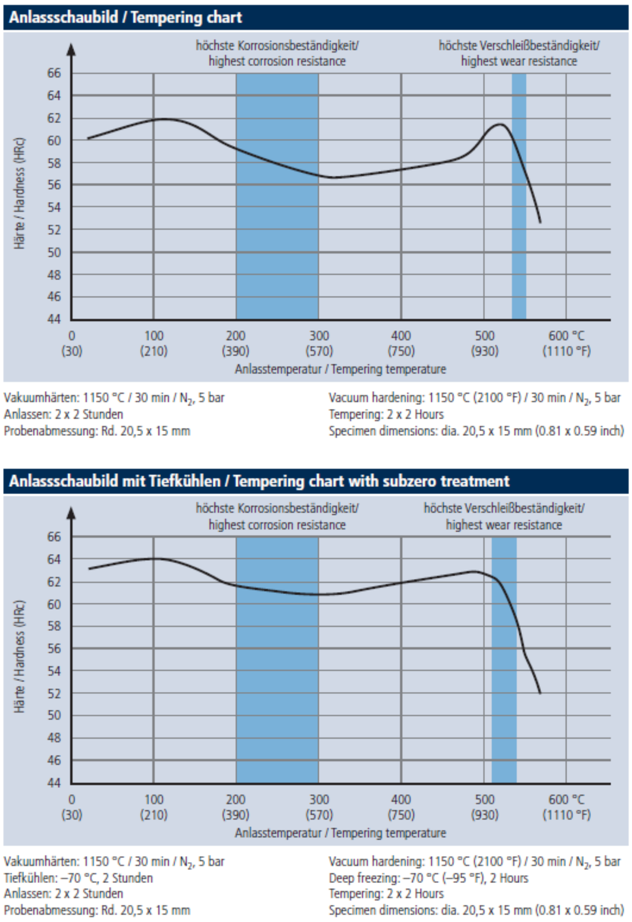

*Fig. 1 Tempering diagram –M390 steel – vacuum hardening at 1150 °C / 30 min/N2, 5 bar, tempering 2*2 hours, cross section of specimen: ø 20.5 * 15 mm [2]*

Material is delivered with 280 HB hardness.

Thermal processing:
Hardening is suitable at temperatures 1100 °C – 1180 °C. After through-heating of whole cross section, Holding time 20-30 minutes for hardening temperature 1100-1150 °C, 5-10 minutes at a hardening temperature 1180 °C. Cooling in the oil / N2. For tempering for highest corrosion resistance a sub-zero treatment for transformation of retained austenite, slow heating for tempering temperature – furnace time 1 hour for each 20 mm of material wall thickness, but minimum 2 hours at temperatures 200 – 300 °C is necessary. Producer recommends tempering of the material min. two times.
If it is necessary to have material tempered for achieving highest abrasion resistance the material must be cooled down below 0 °C for elimination of retained austenite and its transformation to martensite immediately after hardening. It is important also to take care of the shape of the tool after the hardening because there is a risk of the stress cracking. If the material is freezed the hardening at temperature 1150 °C and more is demanded. Slow heating is required for tempering – 1 hour for each 20 mm of material thickness but min. 2 hours. Tempering is recommended to realize min. 3 times and the third tempering is important for achieving complete transformation of retained austenite. Temperature is chosen 20 °C over secondary hardness [2].

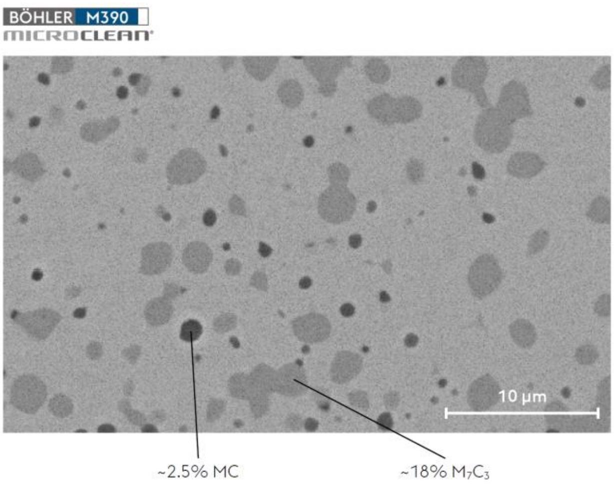

Fig. 2 M390 powder metallurgy steel (PMS)Microstructure [3]

2.2 Böhler M398 Microclean© powder metalurgy steel and its properties

Material M398 has following composition and properties:
Composition of the steel: 2.7% C, 0.5% Si, 0.5% Mn, 20% Cr, 1% Mo, 7.2% V, 0.7% W
Density at 20 °C – 7.46 kg/dm3
Thermal conductivity – 15.2 W/(m.K)
Thermal expansion between 20 °C and
20 °C - 100 °C - 10.4 x 10-6 m/(m.K)
20 °C - 200 °C - 10.6 x 10-6 m/(m.K)
20 °C - 300 °C - 10.9 x 10-6 m/(m.K)
20 °C - 400 °C - 11.2 x 10-6 m/(m.K)
20 °C - 500 °C - 11.5 x 10-6 m/(m.K)
Material is delivered with 330 HB hardness.
Thermal processing:
Hardening is suitable at temperatures 1120 °C – 1180 °C. After through-heating of whole cross section, Holding time 20-30 minutes at hardening temperature 1120-1150 °C, 5-10 minutes at hardening temperature 1180 °C. Cooling in the oil / N2.
During the tempering for achieving of maximum corrosion resistance sub-zero treatment for transformation of retained austenite, then slow heating to tempering temperature, furnace time 1 hour for each 20 mm of wall thickness but minimum 2 hours at temperatures 200 – 300 °C is necessary. Producer of material recommends to repeat tempering at least two times.

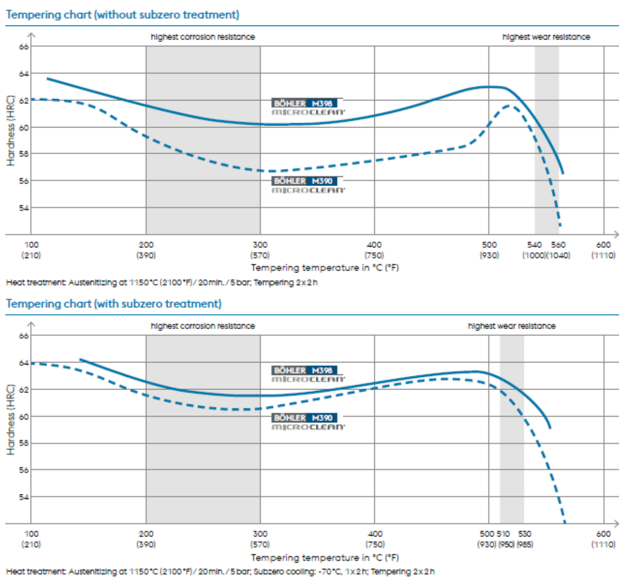

Fig. 3 Tempering diagram of M 398 steel [3]

Tempering for achieving of highest abrasion resistance also requires subzero treatment of material to eliminate retained austenite and its transformation to martensite immediately after hardening. It is necessary to consider the shape of the tool, because there is a risk of stress cracking. In case that material is freezed it is important hardening at temperatures 1150 °C or more. For tempering slow heating is chosen to tempering temperature, holding time 1 hour for each 20 mm of wall thickness, but min. 2 hours. Tempering is recommended to repeat min 3 times and the third is necessary to achieving complete transformation of retained austenite. Temperature is chosen 20 °C over the max. secondary hardness [3].

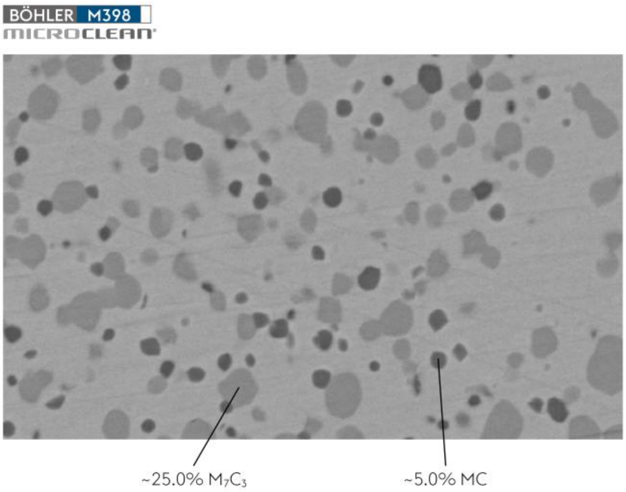

Fig. 4 M398 PMS Microstructure [3]

2.3 Optical microscopy

For analysis of materials was as first chosen optical microscopy. Samples were investigated by optical microscope NEOPHOT 32, linked with attached digital camera Canon from which the photos were transferred to connected computer.

Basic etching for highlighting of material structure was done by mixture of hydrogen nitrate (1-5 ml) and ethyl alcohol (95 ml), well known as a Nital. Samples were etched in Nital for 30 seconds. Then was washed by distilled water, alcohol and after that dried by hot air [9]. Due to excellent anticorrosion properties of materials the structure etched by Nital was nearly impossible to highlight the material structure.

On the surface (Fig.5) there was visible only mixture of darker and lighter grey blotches without any sharp differentiation. The deeper analysis of surface was not possible.

Due to these properties a mixture of acid and glycerine as an etcher had to be prepared:

10 ml HNO_3 + 20 ml HCl + 20 ml glycerine + 10 ml H_2O_2.

Samples were etched for 10 seconds, followed by washing with distilled water, alcohol and dried by hot air to remove the rest of liquids from the surface of sample.

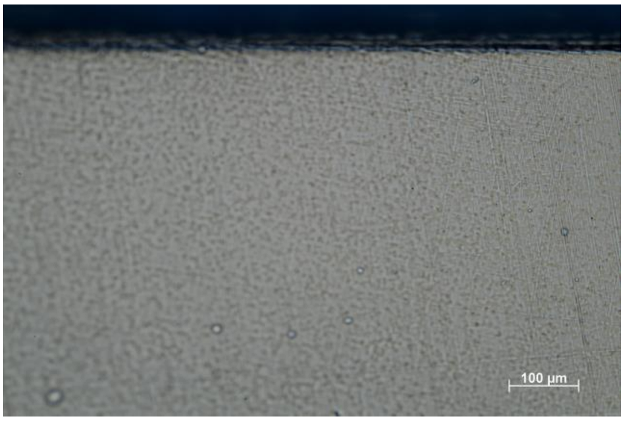

Fig. 5 Material M390 structure etched by Nital

New mixture helped to highlight the structure to state when it should be investigated under the optical microscope. Even the structure was visible, edges of structure was sharp, the analysis was problematic because of smooth material structure. Due to a structure smoothness the magnification 1000 x was chosen. On the sample of M390 (Fig. 6) we can see structure consisting of light and dark dots. The light dots seem as the base material, dark dots are in most probably way carbides of Chrome and other components. Deeper analysis from optical microscope photography is not possible.

On the sample of M398 (Fig. 7) there is visible similar structure as on M390 – dark and light dots. Even the material structure is alike there is visible difference especially in the range of dark dots. M398 has higher volume of dark dots what corresponds with its partially different composition, mostly represented by carbides of Chrome and other components based on higher Carbon content – 1.9% M390 / 2.7% M398.

Comparing the material structure from brochures (Fig. 2, Fig. 4) with material structures obtained by optical microscopy (Fig. 6, Fig. 7) shows that our assumption of the material structure of both materials are right, even that we are not able to look closer.

As a simple matching of structures of powder metallurgy materials and standard way produced material there is photography of grey cast iron structure (Fig. 8). With comparable magnification the structures are completely different in way of components formation visibility. While in PMS steels there are visible only light and dark dots, the formations of grey cast iron components are clearly visible – basic material and formation of Carbon. This structure was added for better perception of the smoothness of

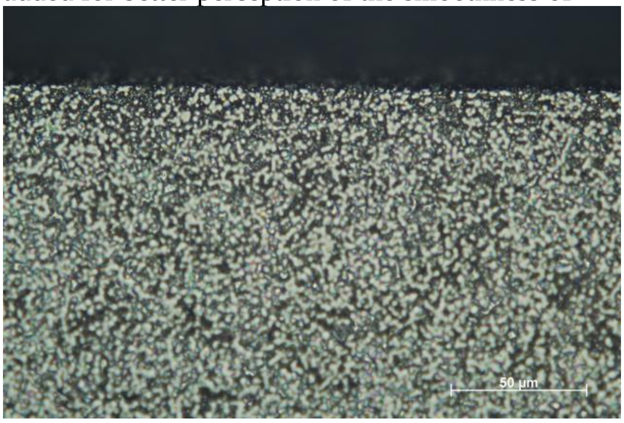

Fig. 7 Structure of Böhler M398 Microclean® material etched by glycerine mixture

Fig. 8 Structure of grey cast iron for comparing with the structure of M390 a M398

2.4 Wear and chemical resistance of M390 and M398 steels

Fig. 9 Hardness and volume loss of M390 and M398 from the tests of material producer [3]

Both materials have much better anticorrosion and anti-abrasive properties in comparison with standard steels, which are the results of its process of production and content. In regard the M398 is a new material with development based on experiences with M390, its properties are in abrasive field increased so much that overcomes M390.

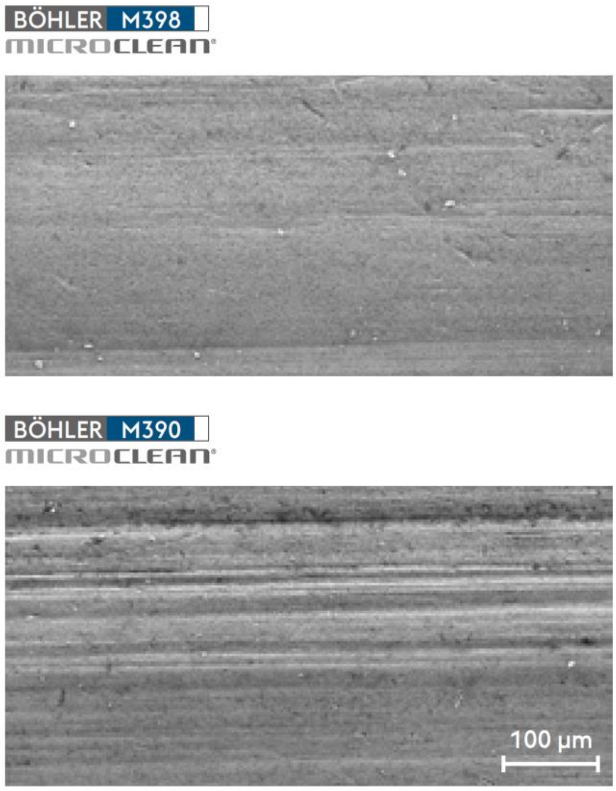

Fig. 10 Wear of materials M390 and M398 from the test at producer - company Böhler [3]

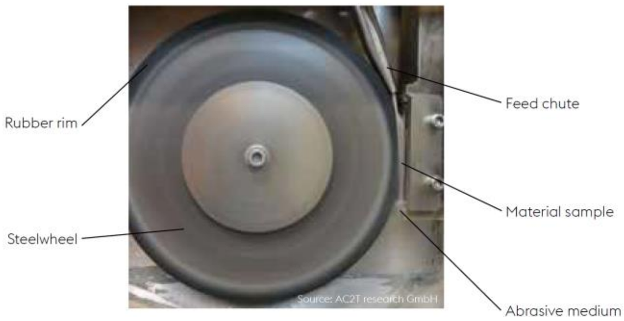

Fig. 11 Device for testing of abrasive wear: Test load 130 N, Sand grain size 100-400 µm, Feed rate 340 g/min, Sliding distance 4309 m [3]

From the producers data it is visible that M398 has much more better resistance against abrasive wear than M390, it is harder but has lower toughness.
Higher hardness and wear resistance should be anticipated from the samples appearance (Fig. 2 and Fig. 3). Higher value and densely placing of the carbides is clearly visible. According to Andreas Blutmager et al [5] carbides have influence on material resistance against wear by protecting basic ferrous matrix, which is washed away during the abrasive wear while carbides position stays nearly the same.

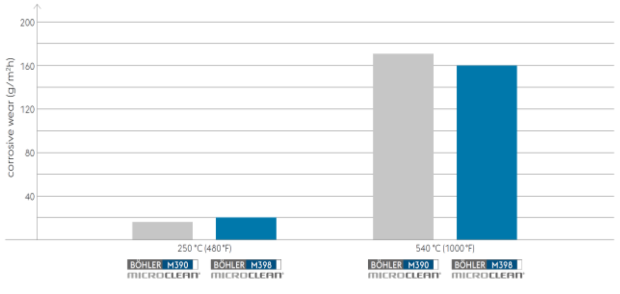

Fig. 12 Comparison of corrosion resistance of M390 and M398 steels [3]

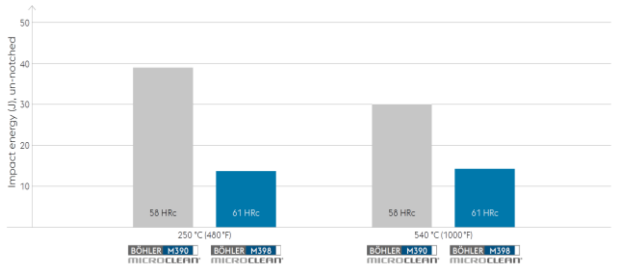

Fig. 13 Comparison of impact energy and hardness of materials M390 and M398 [3]

3 Results and discussion

From the production practice came a demand for simple and cheap material properties improvement for M390 steel – nitridation or some similar thermal or thermochemical treatment which would improve wear resistance while preserving or also improving the corrosion resistance. Nitridation of stainless steel with high Chromium content has some dangers. Three basics are following:

1. At anticorrosion steels with Chromium content comes to decreasing of the corrosion resistance by the influence of Chromium precipitation what causes depletion of surface layer for Chromium which decreases the corrosion resistance. [6]
2. The second risky case is high temperature during the thermal treatment. Within the effort of preserving the best material properties it is necessary to keep the nitridation temperature as low as possible (around 450 °C), what reduces the diffusion of the Nitrogen to surface layer. [7] [8]
3. Enormous grain growth during the long-term thermal treatment can cause mostly loss of mechanical, but also anticorrosion properties while the corrosion can grow between the grain borders.

As visible on the material surface (Fig. 6, Fig. 7), there is enormous number of Chrome carbides and other carbides, too, which can be during improper thermal / thermochemical treatment lost what should open the way for corrosion. Therefore the proper treatment have to be found.
From the main three reasons mentioned above there is necessary to search for technologies which are able to keep the demanded conditions and ensure sufficient diffusion of Nitrogen altogether with lowest segregation of Chromium and keep the grain growth under control.

4 Conclusions

In regard of lack of information about the corrosion of PMS steels and stainless steels in standard literature we had two main goals of this article. The first was to investigate the scientific databases and find the best possible sources, compare its results and find coherences between used methods and materials. In available literature, mainly at scientific articles in Scopus and Web of Science databases methods were found which should have important contribution for nitridation of M390 and M398 materials. It bargains for high density plasma nitridation which was tested on corrosion resistant steel by I. Braceras et al. [6]. This method achieved on the surface of corrosion resistant steel 1.4545 compact layer without cracks (commonly occur during the nitridation) able to resist corrosion influences better than basic surface.
Electrochemical nitridation, which properties presented in their works LV Jinlong et al. [7] According to authors it forms a passive compact layer that

helps to increase the corrosion resistance. This method uses lower temperatures as common nitridation what helps to decrease precipitation of anticorrosion components, especially of Chromium. Simple direct nitridation route at low temperatures, used by A. S. Hamdya et al. created outer layer with new type of nitride so called S-phase, characterized by high hardness and corrosion resistance. [8] Similar as formerly mentioned technologies the simple direct nitridation route has a work temperature at around 450 °C. If the temperature is increased to 600 °C corrosion resistance decreased. Very interesting should be a cooperation with company Rübig concerned in thermal treatment including nitridation. Their technology Plapol looks very attractive. It is necessary to investigate these methods deeper. The question is which technologies will be available during the research and also where the borders of technologies are shifted from the time of cited literal sources creation.

The second goal was to analyse samples of PMS steels M390 and M398 by the optical microscope. Even that the result is not sufficient and for more detailed view we have to use scanning electron microscope, we were able to contemplate the differences between these materials – mainly visual ratio of dark dots (carbides) and light dots (basic material) which show us difference between M390 and M398. As declared from producer the M398 contains more Carbon and Carbides and it is harder with higher wear resistance what is supported by visual observation of samples under the optical microscope. Analysis showed the very fine structure of both materials in comparison with standard materials as grey cast iron and others. Based on that it is visible and it is understandable that the PMS steels has much better physical properties than standard materials due to different kind of production which helps to prevent the lack of relatively big impurities or formation of material components.

We will continue in material investigation because we have to confirm or disprove the outputs from available literature sources which can bring us important findings.

5 Acknowledgement

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