PM PLASTIC MOULD STEELS – WEAR RESISTANT AND CORROSION RESISTANT MARTENSITIC CHROMIUM STEELS

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Abstract Today many different PM tool steels are produced. One important group of these steels are PM plastic mould steels. The great demand for steels for plastic processing is the consequence of increasing use of plastic in daily life. The wide range of applications of plastic mould steels include the foodstuff industry, the chemical and the medical industry. These varied applications demand many different properties. The most important properties of plastic mould steels are wear resistance, hardness, toughness, corrosion resistance, polishability and machinability. Due to the use of plastics with more and more aggressive additives, which attack the surface of the tools, the requirements on plastic mould steels, in particular wear and corrosion resistance, increased in the last few years. Therefore all steel manufacturers are very interested in the development of new alloys for these uses. One way to improve some properties is a variation of the chemical composition, especially concerning carbide and nitride forming elements. To realize the new alloys, powder metallurgy is absolutely required. To keep the experimental effort manageable, the development of new alloys is supported by thermodynamic calculations. The phase diagrams so calculated predict the microstructure and permit first conclusions about the properties. This paper presents results of the investigation of some commercial alloys to get an overview of the present state of the art in the field of powdermetallurgically produced martensitic stainless steels for plastic processing.

Keywords: STAINLESS TOOL STEEL, CORROSION RESISTANCE, WEAR RESISTANCE, MARTENSITE, POWDER METALLURGY, PLASTIC PROCESSING

INTRODUCTION

Plastic mould steels became an important part in the field of stainless tool steels during the last years. The area of application extends from components for the plastic-processing industry like moulds and extruder screws [1] to components for the glass-processing industry (e.g. plungers for production of TV panels [2]), for medical and pharmaceutical applications (e.g. bone files [3]) and for the food processing industry (e.g. fish knives [3]). Figure 1 shows some applications of martensitic chromium steels.

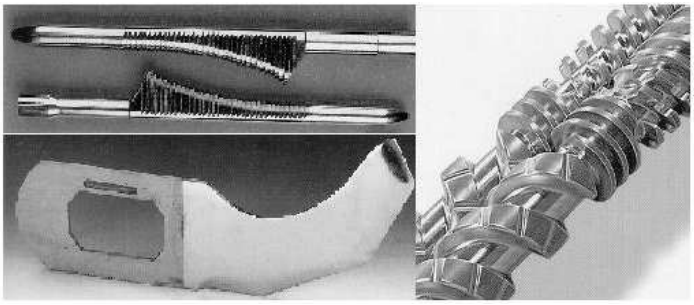

Figure 1. Applications of martensitic chromium steels.

Therefore the requirements on plastic mould steels are very different, Fig. 2. One of the most important properties is an excellent wear resistance. To improve strength and wear resistance, a higher matrix hardness and precipitations of hard carbides and nitrides are necessary. Toughness properties must be sufficient to guarantee good workability. Thus good homogeneity and fine and homogenously distributed precipitations are required. This influences the polishability in a positive manner and only under such conditions can an excellent surface quality be achieved [4]. Corrosion resistance is an important property in many areas of application. Better resistance to pitting corrosion, crevice corrosion and general corrosion are in demand.

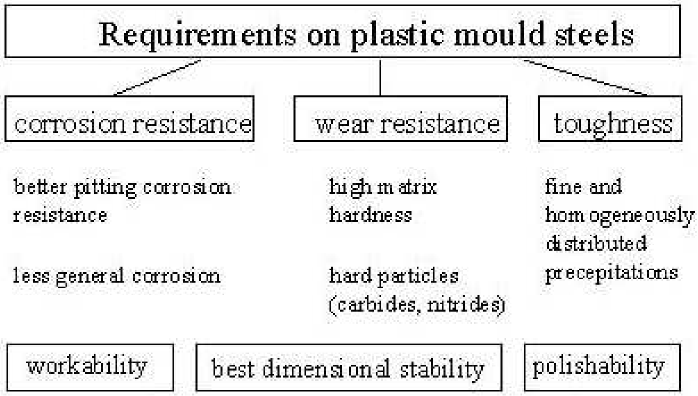

Figure 2. Requirements on plastic mould steels.

Simultaneous attack of corrosion and wear on tool surfaces require materials with excellent wear and corrosion resistant properties. Due to the increase in capacity of plastic processing machines and the processing of more and more filled plastics, it is a matter of urgent necessity to develop new and better alloys in this field.

PM PLASTIC MOULD STEELS

To develop new alloys for applications in the plastic processing industry, it is necessary to know the present state of the art. Therefore competing commercial materials were investigated concerning hardening and tempering behaviour, corrosion resistance, toughness and wear resistance. All the materials tested in the present investigation are iron-based alloys with different contents of hard phases, Table 1.

Table 1. Alloy, steel producer and chemical composition

Alloy	Steel producer	C	Cr	V	Mo	Si	Mn	W	Nb
Elmax	Uddeholm Tooling	1.7	17	3	1	0.4	0.3		
M390PM	Böhler Edelstahl GmbH	1.9	20	4	1			0.6	
CPM420V	Crucible Industries	2.2	13	9	1				
Fe64K	imt / Bodycote	2.6	26	2.7	1.1	0.6	0.4		1.5
Supracor	Crucible Industries	3.75	24	9	3	0.9	0.5		

HARDENING AND TEMPERING BEHAVIOUR

The hardness of the alloys is a decisive aspect concerning an excellent wear resistance. Therefore a minimum hardness value of 58HRC is required. Figure 3 shows the hardening and tempering behaviour of the PM plastic mould steels, those chemical composition is shown in Table 1.

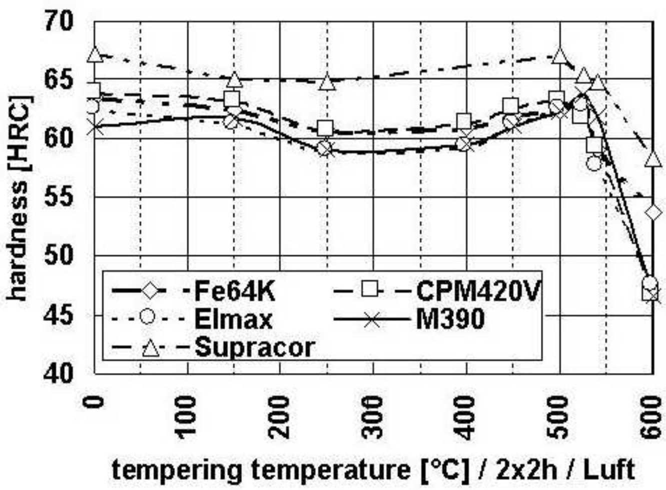

Figure 3. Hardening and tempering behaviour of PM plastic mould steels for an austenitizing temperature of 1150 ℃.

After austenitizing at 1150 ℃and hardening in oil, the specimens were tempered twice for two hours. As can be seen in Fig. 3, the hardening and tempering behaviour of these martensitic chromium steels is similar within the investigated temperature range. Only the alloy with high chromium and vanadium content shows higher hardness values up to 67 HRC. The reason is a very high amount of hard precipitates. All materials show a distinct secondary hardness after annealing at 525 ℃.

CORROSION RESISTANCE

For many applications the corrosion resistance is the most important property. Although the plastic materials are not considered as chemically aggressive in general there may be conditions during production that require a high corrosion resistance. To examine the corrosion resistance, two different corrosions tests were carried out.

Pitting corrosion potential. The pitting corrosion potential was measured in 3%NaCl at room temperature. In Fig. 4 the effect of tempering temperature on the pitting potential of the PM steels is shown. After austenitizing and in the lower tempering range it is possible to make rank the alloys. Alloy Fe64K and M390 show the best resistance against pitting corrosion in this corrosive medium whereas the alloys with the highest amount of vanadium perform not so well. All investigated specimens show a very low corrosion resistance when tempered at higher temperatures. This is why tempering temperatures up to 300-400 $°C$maximum are recommended by the suppliers for applications where corrosion resistance is absolutely required.

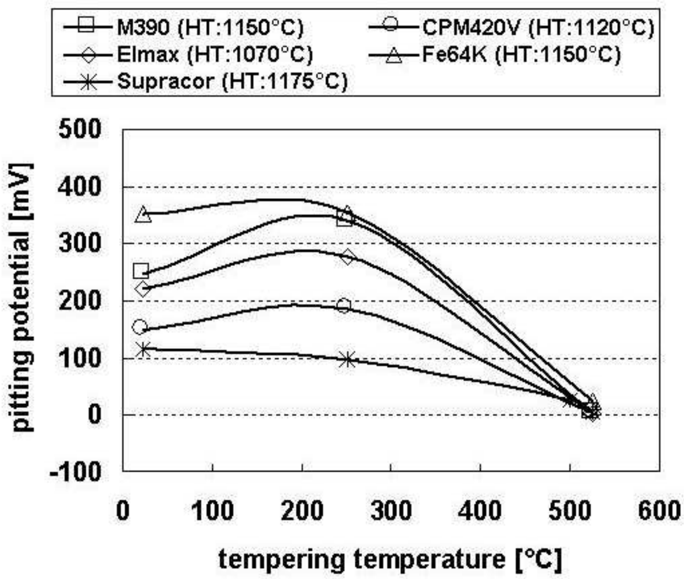

Figure 4. Effect of tempering temperature on the corrosion resistance of PM plastic mould steels.

General corrosion. General corrosion is one of the most frequently encountered forms of corrosion. For testing, specimens are immersed in a corrosive solution. After a fixed time the weight loss of the specimen is determined. The corrosion resistance of the PM steels was investigated in two different corrosive solutions:

Solution A 5% HNO_3 -1% HCl / 3 hours / room temperature

Solution B 10%CH_3COOH / 24 hours / boiling

The results of the measurement can be seen in Fig. 5. The corrosion resistance of all investigated materials in solution A is much worse than in solution B. This is not really surprising because solution A is more aggressive. Fe64K shows the best corrosion properties in both solutions. M390 shows very good corrosion properties in solution A, similar to CPM420V and Elmax. In solution B the corrosion resistance of M390 is as excellent as that of Fe64K. The very good corrosion resistance of Fe64K is the result of the extremely high amount of chromium. But this high alloy content has some disadvantages concerning other properties.

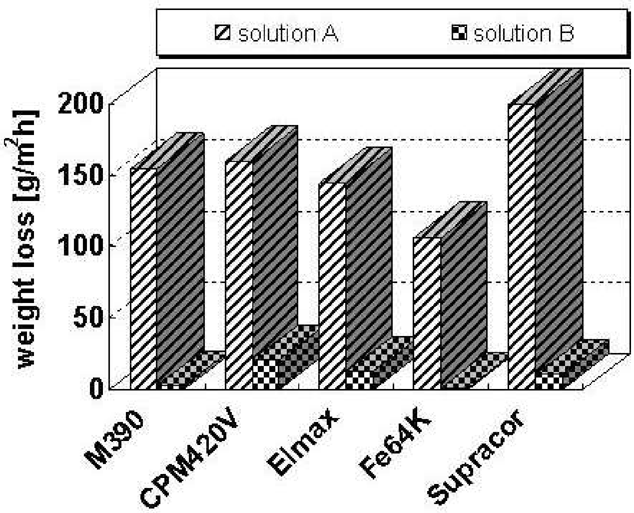

Figure 5. General corrosion of PM plastic mould steels.

The results show that the chemical composition of the matrix is the decisive factor. Enough chromium and molybdenum dissolved in the matrix make sure that the general corrosion resistance is sufficient. It must be considered that the corrosion resistance of tool steels is never an absolute, constant property. It depends on the chemical composition of the steel, on its heat treatment condition as well as on the corrosive agent.

WEAR RESISTANCE

The improvement of wear resistance is one of the most important aims of the development of new plastic mould steels. Especially in regard to the abrasive properties of additives to the highly polymeric materials like glass fibres or other reinforcing or filling materials a high wear resistance of the tool is demanded.

Unfortunately, it is difficult to understand or to define the different wear mechanisms because the processes in the plastics industry are quite complex and some of the parameters are unknown and/or variable throughout the process. In this investigation we have determined the wear resistance of the alloys with a „rubber wheel" abrasion apparatus, shown in Fig. 6. The rubber wheel test is generally used to determine the resistance of metallic materials to scratching abrasion. It is the intent of this method to produce data that will reproducibly rank materials in their resistance to scratching abrasion under a specified set of conditions. Abrasion test results are reported as volume loss in cubic millimeters for the particular test procedure specified. Materials of higher abrasion resistance will have a lower volume loss [5].

The results shown in Fig. 7 indicate that the heat treatment and therefore the hardness value are not the only important parameter for high or low wear resistance. The different amounts and the different kinds of precipitations must be taken into account, too. Furthermore the adhesion of particles in the matrix is an important fact.

Toughness. Toughness is, next to wear and corrosion resistance, a property which must not be ignored. In the event of thermal and mechanical stress during operation, tools can sustain irreparable damage. Therefore impact toughness in a range higher than 30 Joule is required. The impact energy of the selected alloys was determined by an impact bending test. Figure 8 compares the impact toughness of the different materials. Steels such as alloy M390, Elmax and CPM420V achieve an impact energy between 30 and 45 J/cm^2 over the full tempering range. The toughness in the lower tempering range is better than in the tempering range of secondary hardness.

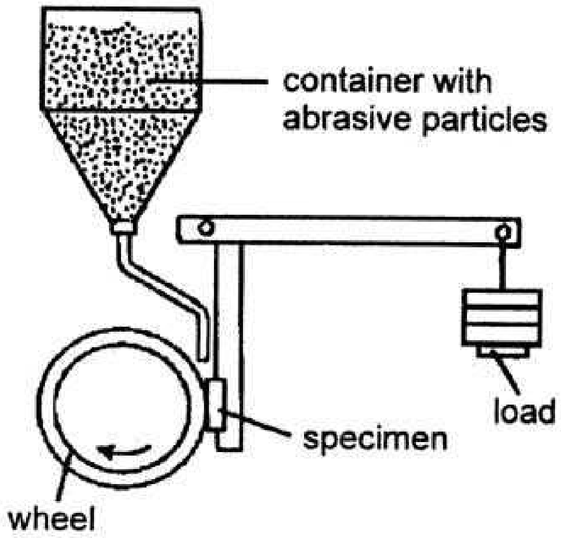

Figure 6. Rubber Wheel apparatus.

But the impact energy is not significantly lower in this field. All three alloys achieve the required toughness values.

However, the alloys Fe64K and Supracor show low impact energy all over the investigated temperature range. A reason for these moderate toughness properties is the very high amount of precipitates (more than 30 volume percent) in both alloys. Alloys Fe64K and Supracor have much lower impact energy at corresponding hardness values than alloys M390, Elmax and CPM420V, Fig 9. It can be seen, that the influence of the amount of hard particles is very important because alloys with the same hardness show different toughness behaviour.

SUMMARY

The sustained growth of the plastic industry and the processing of more and more plastics, filled with aggressive additives, led to market requirements for better corrosion and wear resistant tool steels. Wear and corrosion resistance are the most important properties for steels used in the plastic

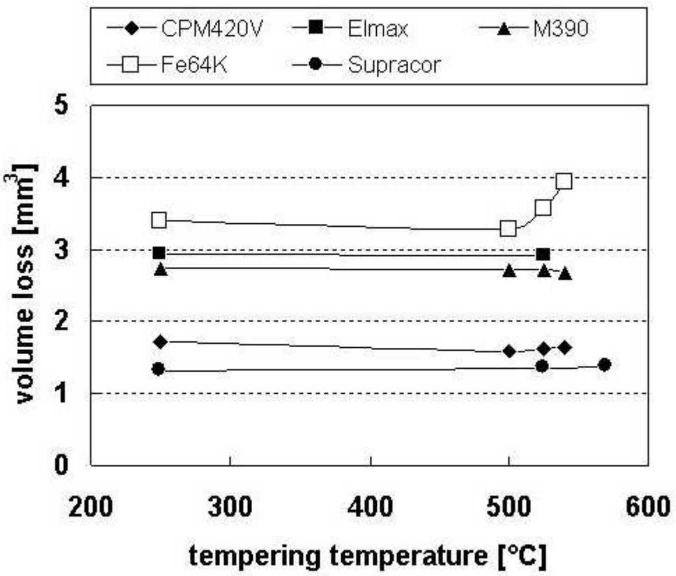

Figure 7. Wear resistance of PM plastic mould steels in comparison.

processing industry. The present state of the art in the field of powdermetallurgically produced martensitic stainless steels is shown. Considering the combination of all desirable properties of stainless tool steels, M390 shows the best overall performance. Powder metallurgy offers new opportunities in the field of plastic mould steels.

OUTLOOK

The data determined in this work serve as a basis for the further development of PM plastic mould steels. The aim of developing new alloys is to combine the best properties of different steels. But it is understood that compromises must be made. The experimental development of alloys is supported by the thermodynamic program Thermo-Calc. It facilitates the calculation of phase diagrams which is very helpful in creating new alloys. Furthermore one can find out the constituents as a function of temperature and the amount of phases in equilibrium at fixed temperature, concentration and activity. Therefore the experimental effort can be kept manageable.

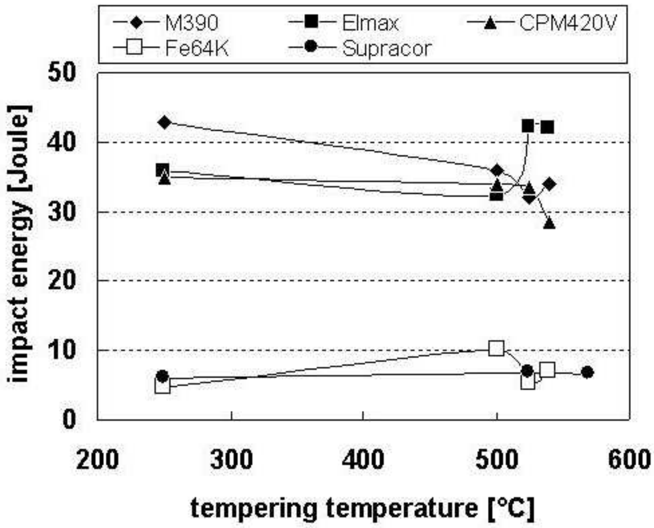

Figure 8. Effect of tempering temperature on the toughness of PM plastic mould steels.

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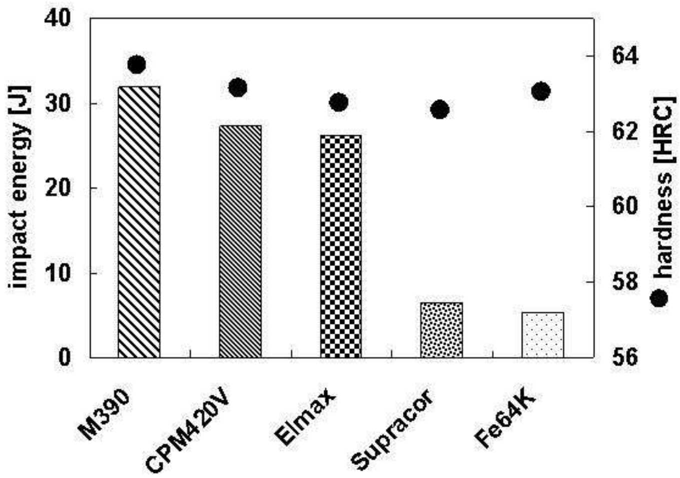

Figure 9. Impact energy of PM plastic mould steels at comparable hardness values.