THE STRUCTURE AND MECHANICAL PROPERTIES OF Mo-Ni AND Mo-Cu
PM STEELS BASED ON DIFFUSION POWDERS

Abstract: The aim of the study was to evaluate the effect of various parameters on the structure and mechanical properties of Mo-Ni and Mo-Cu PM steels based on diffusion powders. Green compacts were single pressed in a steel die at 660 MPa according to PN-EN ISO 2740 standard. Sinterhardening was carried out at 1250°C in a mixture of 95% N₂+5% H₂ for 60 minutes. Half of the samples after sintering were tempered at 200°C for 60 minutes in air. The microstructures of the steels were mainly bainitic. Heat treatment did not affect the mechanical properties of the Mo-Ni steel. After tempering Mo-Cu steel was characterized by better tensile properties (YS 665-708 MPa, UTS 685-735 MPa, HV 0.1 261-341) and similar plastic properties (elongation 1.84-1.88%).

Keywords: PM steels, alloying elements, diffusion powders, heat treatment

1. Introduction

PM steels based on diffusion powders with molybdenum admixed with 0.8% C carbon, characterized by high mechanical properties [1-2], are used for structural parts. Form of introduction of molybdenum has a strong impact on homogeneity and properties of final product. Addition of molybdenum to steel strongly increases its hardenability also. Higher chemical homogeneity is obtained for steels based on Mo-powder added as ferroalloy [3]. At the sintering temperature molybdenum oxides reduce easily [4].

Sintered steels with addition of nickel are characterized by high mechanical properties [5]. Nowadays commercial ferroalloys allow introduction of alloying additions in diffusion bonded form. Pure nickel has negative affect on health and during sintering segregates [6-7].

Steel based on diffusion bonded powder Distaloy AQ with low content of alloying additions (0.5% Mo and 0.5% Ni), processed by Höganäs, was characterized by good tensile properties (UTS 370-580 MPa) and (YS₉₅ 290-390 MPa) [8]. Using another diffusion iron powder Distaloy DH-1 containing of 1.5%Mo and 2%Cu allows us to produce steel with high mechanical properties [9].

2. Material and investigation

Base powders:
- Diffusion iron-powders (produced by Höganäs):
- Distaloy AQ consists of 0.5% Mo, 0.5% Ni, 99% Fe,
- Distaloy DH-1 consists of 1.5% Mo, 2%Cu, 96.5% Fe,
- Graphite powder C-UF (produced by Höganäs).

Two powder mixtures with compositions: Fe-0.5%Ni-0.5%Mo-0.8%C and Fe-1.5%Mo-2%Cu-0.8%C were prepared in a Turbula mixer for 30 minutes. From the powder mixtures, using single-action pressing, tensile test bars according to ISO PN-EN 2740 standard were prepared. Following pressing, sintering was carried out at 1250°C for 60 minutes using hydrogen-nitrogen atmosphere with H₂/N₂ 5-95% ratio. Heating and cooling rates were 75°C/min. and 65°C/min., respectively. After sintering, half of the samples was tempered at 200°C for 60 minutes in air.

Mechanical tests (tensile, bend, hardness) [10] and microstructural investigations were performed. Metallographic examinations were made using Leica DM4000M optical microscope in bright field with total magnification of 500x. The study was supplemented by fractographic investigations carried out on a Scanning Electron Microscope.

3. Results

Table 1 reports densities of green and sintered compacts and the mechanical properties of investigated steels (mean values and standard deviations). Figures 1 and 2 show the microstructures of steels. In Figures 3 and 4 the results of fractographic observations are presented.
Table 1. Densities and mechanical properties of the PM steels – mean values and standard deviations (9 samples per variant)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Chemical composition</th>
<th>Heat treatment</th>
<th>Green density [g/cm³]</th>
<th>Sintered density [g/cm³]</th>
<th>YS₀.₂ [MPa]</th>
<th>UTS [MPa]</th>
<th>E [%]</th>
<th>TRS [MPa]</th>
<th>HV 0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>Fe-0.5%Ni-0.5%Mo-0.8%C</td>
<td></td>
<td>6.84 ±0.02</td>
<td>6.83 ±0.02</td>
<td>422 ±63</td>
<td>522 ±26</td>
<td>3.65 ±0.71</td>
<td>901 ±38</td>
<td>221 ±41</td>
</tr>
<tr>
<td>AQₚ</td>
<td>Fe-0.5%Ni-0.5%Mo-0.8%C tempered</td>
<td></td>
<td>6.85 ±0.01</td>
<td>443 ±42</td>
<td>546 ±26</td>
<td>3.61 ±0.36</td>
<td>897 ±50</td>
<td>232 ±47</td>
<td></td>
</tr>
<tr>
<td>DH</td>
<td>Fe-1.5%Mo-2%Cu-0.8%C</td>
<td></td>
<td>6.83 ±0.02</td>
<td>665 ±18</td>
<td>685 ±42</td>
<td>1.84 ±0.23</td>
<td>1131 ±106</td>
<td>261 ±57</td>
<td></td>
</tr>
<tr>
<td>DHₚ</td>
<td>Fe-1.5%Mo-2%Cu-0.8%C tempered</td>
<td></td>
<td>6.83 ±0.02</td>
<td>708 ±25</td>
<td>735 ±24</td>
<td>1.88 ±0.22</td>
<td>1226 ±131</td>
<td>341 ±32</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. The microstructure of steel Fe-0.5%Ni-0.5%Mo-0.8%C a – without heat treatment; b - after tempering at 200°C for 60 minutes in air:

Fig. 2. The microstructure of Fe-1.5%Mo-2%Cu-0.8%C a – without heat treatment; b - after tempering at 200°C for 60 minutes in air:
Fig. 3. The fractures surfaces of PM steel Fe-0.5%Ni 0.5%Mo 0.8%C a – without heat treatment (mag. 5000x); b - after tempering at 200°C for 60 minutes in air (mag. 3000x)

Fig. 4. The fractures surfaces of PM steel Fe-1.5%Mo-2%Cu-0.8%C a – without heat treatment (mag. 5000x); b - after tempering at 200°C for 60 minutes in air (mag. 5000x)

4. Discussion

Metallographic investigations (Figs. 1-2) allowed us to define the microstructures of the investigated steels. All tested variants were characterized by bainitic microstructures. Steels DH and DHt contained finer carbide dispersions in comparison to steels AQ and AQt. This had an evident influence on properties.

Steels based on Distaloy AQ were characterized by good mechanical properties. Changing parameters (addition of tempering) of AQ steel did not influence tensile and plastic properties. Higher amount of chemical elements in the base diffusion powder Distaloy DH-1, in comparison with Distaloy AQ, caused modification in properties of investigated steels. Steel DH had higher tensile properties and lower plastic properties, what is related to higher hardenability in comparison with steels AQ and AQt.

Based on the fractographic investigations (Figs 3-4), type of fracture of researched steels can be determined. In Fig. 3 fractures of AQ and AQt steels are shown. Fractographic observations of tensile loaded AQ and AQt steels revealed ductile regions. Steel DH was characterized by cleavage fracture surfaces with cleavage steps and river patterns (Fig. 4a). After heat treatment cleavage and quasi-cleavage areas (Fig. 4b) can be observed in steel DHt.
5. Conclusions

From the study it is concluded:

1. Heat treatment in air has not affect on mechanical properties of steel with composition Fe-0.5%Ni-0.5%Mo-0.8%C.
2. Steels based on diffusion powder Distaloy DH-1 were characterized by better tensile properties and lower plastic properties in comparison to steels based on Distaloy AQ.
3. Heat treatment of DH steel caused a slight increase of tensile properties in comparison to DH steel.
4. Investigated steels were characterized by bainite microstructures.
5. Steels AQ and AQt had ductile fractures.
6. Fractographic observations revealed cleavage and quasi-cleavage fractures in DH and DHt steels.

6. Acknowledgments

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7. References