Research on the Impact Toughness of Die Steel through Digital Impact Test

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ABSTRACT: The relationship between loopholes of stress concentrated coefficients and stress consolidate coefficients were illustrated; the relationship between impact value and loopholes sensitivity were found; The relationship between crack forming energy and crack forming life was studied.

1 INTRODUCTION

There are two ways commonly adopted to improve the performance of die steel and prolong its service life. One is to develop new die materials, and the other is to improve the quality of heat treatment with the adoption of advanced technology. Due to large deformation resistance of the material during impact, fierce friction and extrusion are exerted on the working part of the die. Accordingly, the hardness, strength and wear resistance of the die are great, and impact force is imposed on the die during working process. Therefore, due attentions should be paid to the toughness of the die.

Whether impact toughness \( a_k \) (or \( A_k \)), should serve as the index to determine the toughness of material has always been debatable. Impact energy is characterized by the area under the impact-displacement curve, i.e., impact energy is the parameter of impact force and the deformation (displacement) of the specimen under impact force. In this case, when impact energy is unvaried, there could be two conditions: If the impact force is large, the displacement will be small, and the material features brittleness. If the impact force is small, the displacement will be large, and the material features toughness. Therefore, \( A_k \) can not reflect the toughness and brittleness of the material. On that account, \( a_k \), quotient obtained by dividing the energy consumed in fracturing the specimen with the cross-sectional area of the specimen, becomes a pure mathematical quantity, and thus cannot reflect the toughness of the material.

In order to explore the relationship between impact force, displacement of the die and impact energy and its effect on toughness, the impact force-displacement curves at different temperatures are obtained by employing digital impact tester. Besides, analysis and research on the relationships between impact force, displacement, energy of crack formation, energy of stable crack
propagation and the temperature are conducted, so as to measure the impact toughness of die steel with new index of impact performance.

2 EXPERIMENTAL MATERIALS AND CONDITIONS

2.1 Selection of die steel:

The new die steel (HHD) was adopted in this study, and its chemical constituents are: Cr10, Mo2, Ni0.75, V0.8, W0.5, Ti0.3 and Ta0.1.

2.2 Heat treatment:

Quenching was performed at 1080°C, tempering at 580°C

The specimen used in the impact test is specified as follows:

V-type notched specimen with the size of 7mm*10mm*60mm was used.

2.3 Temperatures:

Tests were conducted at the temperatures of 20°C, 300°C and 600°C.

High-precision digital impact tester was employed.

Its functions are as follows: Impact force-displacement, impact force-time, energy-time and displacement-time curves can be accurately obtained. Besides, yield stress Fgy, maximum force Fm, force Fiu initiating unstable crack propagation and force Fa terminating unstable crack propagation are accurately measured. All these are achieved by storing, analyzing and processing the data after the acquisition of forces and displacements during impact. The impact energy is decomposed into energy of crack formation (WI), energy of stable crack propagation (WPI) and energy of crack propagation (WP).

3 DIGITAL IMPACT TEST

3.1 Sampling

The method of multiple specimens was adopted to obtain the results of different stages during the formation of crack, series of impacts on specimens were conducted at different elevations of the pendulum. Specimens demonstrated deformations or cracks of different degrees due to different impact energy and impact force, and some even fractured. Specimens with deformations or cracks of different degrees were sampled through linear cutting, as shown in Figure 1. After
the notched side where linear cutting was conducted was ground, polished and eroded, it was observed under scanning electron microscope to shed light on the relationship between crack formation or crack propagation and the load.

![Figure 1. Cutting of specimens.](image)

### 3.2 Shape of the fracture

Figure 2 is the macroscopic morphology of the fracture of the specimen, with three regions divided. Figure 3 displays the result of analysis of the fracture under JSM-5800 scanning electron microscope.

![Figure 2. Macroscopic morphology of the fracture of the specimen.](image)

(a) The crack was formed at the bottom of the notch around which elastic deformation was obvious, and propagation was along the lath. Size: about 3 um.
(b) The crack extended between the lathes and the boundary of the bundle.

(c) The crack propagated along the boundary of the lath bundle, and was purified, with a cavity near the lath bundle and the boundary.

(d) Cavities formed with the propagation of cracks between bundles or along the boundary, and was connected with fiber under impact force, with some extending through the lathes.

Figure 3. Electronic scanning photo of the fracture's profile.

4 RESULTS AND ANALYSIS

The results of impact tests conducted on HHD die steel at 20°C, 300°C and 600°C are shown in table 1 and table 2.
Table 1. Impact force, displacement and energy of HHD measured by impact tester.

<table>
<thead>
<tr>
<th>Items</th>
<th>Temperatures</th>
<th>$F_{gy}$</th>
<th>$F_{m}$</th>
<th>$F_{iu}$</th>
<th>$F_{a}$</th>
<th>$S_{pl}$</th>
<th>$W_{i}$</th>
<th>$W_{p1}$</th>
<th>$W_{t}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
<td>15.05</td>
<td>22.47</td>
<td>19.57</td>
<td>0.61</td>
<td>2.52</td>
<td>56.74</td>
<td>125.33</td>
<td>185.45</td>
</tr>
<tr>
<td></td>
<td>20°C</td>
<td>16.21</td>
<td>23.79</td>
<td>21.30</td>
<td>0.96</td>
<td>2.29</td>
<td>52.74</td>
<td>126.54</td>
<td>183.70</td>
</tr>
<tr>
<td>Average values</td>
<td></td>
<td>15.63</td>
<td>23.13</td>
<td>20.44</td>
<td>0.79</td>
<td>2.41</td>
<td>54.74</td>
<td>125.67</td>
<td>184.58</td>
</tr>
<tr>
<td></td>
<td>300°C</td>
<td>12.10</td>
<td>18.84</td>
<td>15.86</td>
<td>0.66</td>
<td>3.50</td>
<td>39.69</td>
<td>173.88</td>
<td>220.14</td>
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<tr>
<td></td>
<td>300°C</td>
<td>12.84</td>
<td>20.09</td>
<td>17.73</td>
<td>0.52</td>
<td>2.79</td>
<td>41.94</td>
<td>149.97</td>
<td>197.82</td>
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<tr>
<td>Average values</td>
<td></td>
<td>12.47</td>
<td>19.47</td>
<td>16.80</td>
<td>0.59</td>
<td>3.15</td>
<td>40.82</td>
<td>161.93</td>
<td>208.98</td>
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<tr>
<td></td>
<td>600°C</td>
<td>9.26</td>
<td>15.96</td>
<td>10.55</td>
<td>2.26</td>
<td>4.31</td>
<td>36.86</td>
<td>176.96</td>
<td>222.18</td>
</tr>
<tr>
<td></td>
<td>600°C</td>
<td>9.56</td>
<td>16.49</td>
<td>9.70</td>
<td>2.43</td>
<td>5.50</td>
<td>35.46</td>
<td>206.78</td>
<td>251.58</td>
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<tr>
<td>Average values</td>
<td></td>
<td>9.41</td>
<td>16.23</td>
<td>10.13</td>
<td>2.35</td>
<td>4.91</td>
<td>36.16</td>
<td>191.78</td>
<td>236.88</td>
</tr>
</tbody>
</table>

Table 2. Change rates of main parameters including force, displacement and energy with the increase of temperature.

<table>
<thead>
<tr>
<th>Change rate of relative temperature</th>
<th>$f_1%$</th>
<th>$f_2%$</th>
<th>$f_3%$</th>
<th>$S%$</th>
<th>$w_1%$</th>
<th>$w_2%$</th>
<th>$w_3%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_1=300°C$</td>
<td>-20.2</td>
<td>-15.8</td>
<td>-17.8</td>
<td>30.7</td>
<td>-25.4</td>
<td>28.9</td>
<td>13.2</td>
</tr>
<tr>
<td>$T_2=600°C$</td>
<td>-39.8</td>
<td>-29.8</td>
<td>-50.4</td>
<td>103.7</td>
<td>-33.9</td>
<td>52.6</td>
<td>28.3</td>
</tr>
</tbody>
</table>

It should be noted that $T_0$ is equivalent to 20°C, and the negative value of data represents the reduced percentage.

$$f_1 = \frac{F_{gy}(T) - F_{gy}}{F_{gy}}, \quad f_2 = \frac{(Fm(T) - Fm)}{Fm}, \quad f_3 = \frac{(Fiu(T) - Fiu)}{Fiu},$$

(1)

$$s = \frac{(Sp(T) - Sp)}{Sp}, \quad w_1 = \frac{(W_i(T) - W_i)}{W_i}, \quad w_2 = \frac{(Wp1(T) - Wp1)}{Wp1}, \quad w_3 = \frac{(Wt(T) - Wt)}{Wt}.$$  (2)

Figures 4-7 display the curves reflecting the change of impact force, displacement and energy with the increase of temperature according to data given in table 1 and table 2.
The following results can be obtained through Table 1, Table 2 and the above curves.

1) Yield stress $F_{y}$, the maximum force $F_m$ and force $F_{iu}$ initiating unstable crack propagation all decreased with the increase of temperature. Compared with room temperature, the decrease of force $F_{iu}$ initiating unstable crack propagation demonstrated the biggest amplitude, decreasing by 50.4% at 600°C compared with room temperature. Yield stress decreased by 39.8%, and the maximum force decreased by 29.9%.
2) With the increase of temperature, the displacement (deflection) of specimens increased at large rate, wherein the displacement during stable crack propagation changed most significantly, and increased by 103.7% at 600°C compared with room temperature.

3) With the increase of temperature, energy of crack formation ($W_I$) decreased, with a reduction of 33.5% at 600°C compared with room temperature. By contrast, both the energy of stable crack propagation ($W_{P1}$) and total impact energy enhanced, with increases of 52.6% and 28.3%, respectively, at 600°C.

4) It is commonly known that impact energy can not characterize the toughness of the material. Impact toughness is determined by both the impact force and the displacement. According to the result of the test on HHD die steel, when temperature rose from room temperature of 20°C to 600°C, impact force $F_m$ exhibited a decrease of 29.8%. The force initiating unstable crack propagation decreased by 50.4%, which is mainly caused by the increase of displacement by 103.7% during this process.

5 SUMMARY

This study leads to two conclusions: One is that impact toughness is determined by both the impact force and the displacement during impact. Secondly, it is obvious that energy of stable crack propagation ($W_{P1}$) can serve as the index against which the toughness of material is measured.

REFERENCES


Compiled by Zhou Shunsu, Steel brittleness and brittle fracture of engineering structures, Shanghai Science and Technology Press, 1983, 8.

