Study on the Failure Ratio of the High Carbon Cast Steel Shot

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Abstract

The ERVIN test machine was used in this study to mimic the actual blast cleaning process. The high carbon cast steel shot sample, heat-treated at five different temperatures, are put into a ERVIN tester and ran for predefined cycles. The wearing of the samples were examined under a magnifier. The failure ratio was defined and its influencing factors were studied. The results show that the failure modes, including brittle fracture, surface peeling and core spall, can be analyzed by means of failure ratio represented by the defined weight ratioG_f/G_t, the failure ratio are affected by the heat treatment, ERVIN cycle, microstructure and flaws, particle size, target hardness. Impact velocity and impact angle play important role in the wearing failure process.

Keywords: high carbon cast steel shot; failure ratio; surface peeling; core spall; weight ratio; influencing factors

1. Introduction

From the appearance, it is difficult to distinguish the high carbon cast steel shot samples after different heat treatments, and at present the abrasive manufacturers only provide the technical data and physical characteristics in the data sheet based on related standards[1,2], but the ERVIN life and the wearing failure modes are not given enough importance, hence the author suggests that ERVIN life, the main failure mode and its wearing ratio should be added to the data sheet, which can complete the abrasive standard, provide convenience for the end users to choose the suitable abrasive, encourage the manufacturers to improve their manufacturing process and improve the abrasive quality. But the failure ratio is affected by many factors so that it is necessary to evaluate the failure ratio under the same condition.

2. Samples and the Processing Procedure

The as-cast high carbon cast steel shot sample used in this experiment, manufactured by Shandong Kaitai Metal Abrasive Co., as shown in Table 1, was melted by medium frequency induction furnace and formed by centrifugal atomizing method. The samples were in good spherical shape without irregular forms and cracks. The box resistor stove was used as the heating device and water was used as the cooling medium. The samples were etched by the alcohol solution with 4% of nitric acid and then studied for the microstructures using a metalloscope. The micro hardness of the samples were tested by the vickers hardness tester with a 500g load. As shown in Table 1 and Table 2, five high carbon cast steel shot samples, undergone five various heat treatments, were prepared for this study; the samples, tempered at 150°C and 550°C and double quenched at 840°C, were run in ERVIN test machine for 500 cycles, 1000 cycles and 1500 cycles respectively. 20g samples were used in each run for clear observation of the wear failure morphology and hence easy assessment of the failure ratio.

Table1 Characteristics of as-cast high carbon cast steel shot

Composition (wt%)	0.88C 0.64Si 0.67Mn 0.024S 0.026P
Microstructure	Martensite and Retained austenite
Size (mm)	1.7（S550）
Hardness（HRC）	60.2

Table2 Characteristics of four heat-treated high carbon cast steel shot samples

Heattreatment	Hardness HV(HRC)	Microstructure
Tempering 550°C×0.5h	430.8 (44.6)	tempered sorbite and carbides
Quenching 840°C×0.5h	803.8 (64.1)	cryptocrystalline martensite, retained austenite and unsolvable granular carbides
Quenching 840°C×0.5h Tempering 150°C×0.5h	730.0 (61.4)	tempered martensite
Quenching 840°C×0.5h Tempering 550°C×0.5h	377.0 (40.0)	tempered sorbite

3. Experiment Results and Analysis

3.1 The Representation of the Wearing Ratio

In order to effectively characterize three main failure modes, the weight ratio is chosen to describe these failures. The weight ratio is defined as G_f/G_t, where G_t is the total weight of the sample and G_f represents G_b, the weight of the particles in brittle fracture, G_s, the weight of the particles in surface peeling or G_c, the weight of the particles in core spall respectively. The particles defined as core spall can be further categorized into those failures with broken rim region (G_{cr}) and those with many small fragments in the core region (G_{cc}), so G_c is the sum of the above two parts, i.e. $G_c=G_{cr}+G_{cc}$. If G_{ml} is defined as the mass loss, we get this equation: $G_t=G_b+G_s+G_c+G_{ml}$.

3.2 Influencing Factors

3.2.1 Heat Treatment

The heat-treatment process determines the hardness, micro-structure, ERVIN life, wearing failure mode and its ratio of the high carbon cast steel shot. The wearing failure mode of the as-cast sample is shown as brittle breakdown. After double quenching at 840 °C for 30 minutes, the dendrites structure of the sample were improved or eliminated, there was only a small proportion of the sample shown brittle fracture, most worn samples where either in the form of surface peeling or core spall. After double quenching at 840°C and then tempering, the hardness of the sample was further decreased and impact resistance or toughness was also increased, the failure modes of these samples were exclusively surface peeling and core spall.

In Table 3, the failure mode and its ratio of two groups of samples, undergone different heat-treatment process, are listed. These samples were run for 500 ERVIN cycles and then screened through a sieve with 0.6 mm aperture mesh. The failure modes and its ratio of the first group of sample, which were tempered at 150°C after quenching at 840°C, consists of 15% surface peeling, 84% core spall and very few brittle fractures. This group of samples have the hardness of 730 HV and the ERVIN life of 1573 cycles. The failure mode and ratio of second group of sample, which were tempered at 550°C after quenching at 840°C, consists of 60% surface peeling and 40% core spall. These samples have the hardness of 377 HV and the ERVIN life of 3610 cycles. The result shows that after increasing the tempering temperature, the hardness of the sample decreases and the ERVIN life of the sample is improved. Furthermore G_s/G_t increases but G_c/G_t decreases. The higher tempering temperature it is the better impact resistance and toughness and the better structure uniformity. We can also get the conclusion that the larger G_s/G_t, the longer the ERVIN life.

Table 3 Relationship between failure ration and heat treatment process

Heat treatment (after quenching 840°C×0.5h)	Proportion after 500 cycles（wt%）			Hardness	ERVIN life
	G_b/G_t	G_s/G_t	G_c/G_t	HV (HRC)	（cycle）
Tempering 150°C×0.5h	1	15	84	730.0 (61.4)	1573
Tempering 550°C×0.5h	0	60	40	377.0 (40.0)	3610

3.2.2 ERVIN cycle

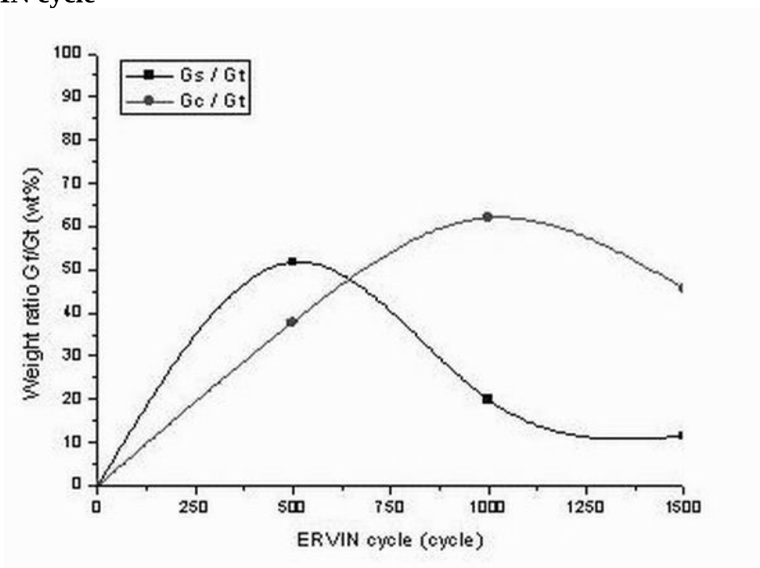


Fig.1. Relationship between failure ratio and ERVIN cycle

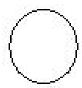
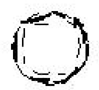
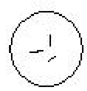
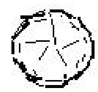
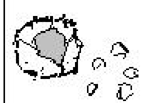
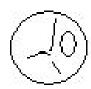
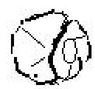
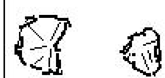
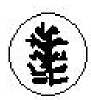
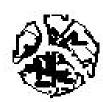
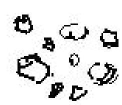
In Fig. 1, three batches of samples, prepared by quenching at 840°C and then tempering at 550°C, were put in Ervin test machine and run for 500, 1000 and 1500 cycles respectively. These samples were then screened by a sieve with a 0.425mm aperture. After 500 cycle run, 52% particles are in multi-facets sphere shape which represents the surface peeling, G_c/G_t is 38% and the residual powder is 10%. While the ERVIN cycles increases to 1000 cycles, G_s/G_t decreases to 20%, but G_c/G_t increases to 62% and is bigger than G_s/G_t, it shows that there were particles show in the form of core spall. When the ERVIN test runs up to 1500 cycles, both G_s/G_t and G_c/G_t decrease to 11.5% and 45.5% respectively, and G_c/G_t is larger than G_s/G_t, because particles in surface peeling change to core spall while particles in core spall fracture turn into debris. It is concluded that at a lower ERVIN cycle, G_s/G_t plays an important role; while the test cycle increases, G_c/G_t takes a leading position; at higher ERVIN cycles, both G_s/G_t and G_c/G_t decrease.

3.2.3 Microstructure, flaws and particle size

Table 4 shows the relationship between failure mode vs. microstructure and flaws of the sample. The ERVIN cycle, a comparative value or number determined by sample's ERVIN life, is chosen to assist the analysis of the failure process. Shot in dendrite structure, namely the as-cast state, with a larger number of small flaws will be fractured as in the brittle failure mode even at a very low 30 ERVIN cycles. Shot with large cracks or voids will generate a fatigue massive split at the low to medium ERVIN cycle and fractured at a high ERVIN cycle. The high carbon cast steel shot in a uniform structure with farthing flaws will be worn in surface peeling even at a higher ERVIN cycle or in the multi-facets sphere shape all along, wherein if the high carbon cast steel shot is in a uniform structure with little flaws, it will be worn in surface peeling at a low ERVIN cycle,but in core spall at higher ERVIN cycle..

For the high carbon cast steel shot samples with most particles are of an even structure and very few flaws, only surface peeling occurs at the low ERVIN cycle, about 100 cycles, and the core spall will show up after 500 cycles, eventually the sample will be fractured at a higher cycle run. It is known that larger particles contain larger number of flaws[9], so that sample with larger diameter incurs a larger G_c/G_t at a lower ERVIN cycle than the sample with a smaller diameter.

Table 4. Failure mode vs. microstructure and flaws

before use	Low ERVIN cycle	High ERVIN cycle	Wear failure mode
			Surface Peeling
			Core Spall
			Massive Split
			Brittle Fracture

3.2.4 Target hardness、impact velocity and impact angle

In this experiment, ERVIN test machine was used to mimic the blast cleaning equipment so that the target hardness, impact velocity and impact angle are fixed value. In real applications, different work pieces with various hardness and blast cleaning effect need different impact velocities and impact angles. When a target hardness is high, it does not deform easily[6] and it absorbs little kinetic energy, while the shot itself keeps the larger part of the kinetic energy to rebound and deform occurring the failure process; it can be concluded that under the same condition, the particle impacted to a hard target will have a larger G_c/G_t than a soft target. If the target hardness is a constant, the larger the impact velocity is, the larger kinetic energy the particle has[9], furthermore it has been proven that the fracture probability increases when there is an increase in the impact velocity and increase in the impact angle (Rumpf(1965) and Rupple and Brauer (1990)) [9]; therefore under the same condition, a larger impact velocity and a larger impact angle will generate a larger G_c/G_t.

4. Conclusion

For the high carbon cast steel shot, the failure ratios of brittle fracture, surface peeling and core spall can be represented by the weight ratio G_f/G_t, and affected by the heat treatment process, ERVIN cycle, microstructure and flaws, particle size, target hardness, impact velocity and impact angle. G_f/G_t plays an important role in the shot wearing process and determines the shot consumption directly, the author suggests that G_f/G_t and ERVIN life should be added to the data sheet of the product. It will benefit the end users and also drive the manufacturers to improve the quality of their products.

5. References

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