Advance Journal of Food Science and Technology 11(11): 745-749, 2016
DOI:10.19026/ajfst.11.2774
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: August 5, 2015 Accepted: September 3, 2015 Published: August 15, 2016

Research Article

Fracture Toughness and Hardness of Food-can Iron Using Powder Metallurgy at Room Temperature

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Abstract: Fracture toughness and hardness of food-can iron powder metallurgy under tensile loading was studied using SEM. The result showed that strain of samples changes is very small, while obvious yield phenomenon is not observed. Propagation rate of damage samples is higher than without damage samples and the propagation rate of samples increases with depth of prefabricated notch increasing. The stress intensity factor reaches the threshold value when strain reaches 2.7. Fracture toughness decreased because of damage and the greater strain was needed in order to increase fracture toughness. Energy release rate of damage samples is smaller and energy release rate of samples increases with depth of prefabricated notch increasing. The hardness is higher at the loading region and hardness of the sample decreases from the loading region to the fracture region. Higher density samples have higher hardness.

Keywords: Food-can iron, fracture toughness, powder metallurgy

INTRODUCTION

Compared with the traditional metal, the unique structure characteristics of Powder metallurgy materials make the physical and mechanical properties have undergone significant change. Cracks of components in engineering often occurred and the occurrence of cracks would cause great impact components. Therefore, the research of components is necessary to crack propagation. Recently, research on the development of hardness and fracture toughness of materials has been considered as a subject of interest due to conduct to enhance properties of materials (Ehsan *et al*., 2011). However, research of crack propagation is assessed by fracture toughness in addition to conventional mechanical properties. A lot of research of fracture toughness and hardness were studied by many scholars. Wang and Yu (2007) studied the dynamic fracture toughness of martensitic stainless steel welded joints. By measuring the hardness distribution and micro fracture changes, the reasonable welding technical measures were determined ultimately. Pantelakis *et al*. (2007) presented properties of the hardness is gradually increased with fatigue stress increasing. Siddheswaran *et al*. (2012) investigated the mechanical properties such as micro-hardness, fracture toughness by the Vickers indentation method. It was found that the crack mode observed during the indentation on the samples belongs to median cracks. Zhou *et al*. (2006) studied the deformation and fracture toughness of Ni-P by the indentation method and notched film tensile samples. Pantelakis *et al*. (2007) found that level degree of hardening increases with increasing fatigue stress. Failure by tensile loading continues to remain the most serious concern for structural failure of components despite the exhaustive amount of past research (Pantelakis *et al*., 2007). However, fracture toughness and hardness of food-can iron powder metallurgy for different densities under tensile loading also does not be involved. In the text fracture toughness and hardness of food-can iron powder metallurgy for different densities were researched under tensile loading, in order to provide theoretical guidance for fracture mechanism of food-can iron by powder metallurgy.

MATERIALS AND METHODS

The investigations were performed on the food-can iron powder metallurgy, the strain fracture and tension tests of the food-can iron were carried out. After testing the specimens were offered to the author of this study. The samples of food-can iron were fabricated using method of powder metallurgy, provided by university of Wuppertal and undergone rolling process and annealing (Baron, 2012). *In-situ* observation samples were fabricated by wire cutting method. Size of the material was 35 mm*16 mm*2 mm. All tensile experiments were carried out at constant room temperature (25±3°C), in order to investigate the fracture toughness during tensile loading all experiments were observed by using an environmental scanning electron microscopy. The fracture

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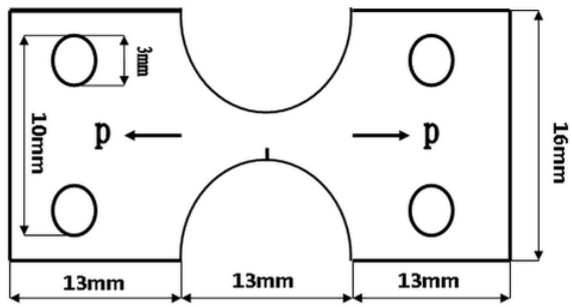

Fig. 1: Dimensions and loading state of the samples used for the in situ ESEM observations

mechanisms of the powder metallurgy food-can iron were investigated during dynamic changing process under tensile loading by SEM. Measurements of fracture toughness performed at room temperature using a tensile testing machine at across speed of 2 mm/min. During the experiments the tensile load/displacement relationship was recorded until failure of the test specimen occurred. The results of the measurements were statistically evaluated in accordance with the samples. Hardness of the samples was measured from fracture to the ends of the sample. The pre-cracking tensile specimens were machined. The size and force states of the samples were showed as Fig. 1.

RESULTS AND DISCUSSION

Stress-strain curve of the samples are showed as Fig. 2. Strain variation of the samples is very small and strain change from 0 to 0.25. Stress is proportional to strain at ε = 0.03, afterwards the samples occur yield phenomenon. When ultimate strength reaches 270MPa at ε = 0.19, the samples occur to fracture quickly. Process of plastic deformation is no obvious and elongation of the sample is only 3.3%. Compare to armco iron, ultimate strength and fracture process change obviously. Mechanical Properties of the samples are listed as Table 1.

Table 1: Mechanical properties of the food-can iron samples fabricated by powder metallurgy

Sample number	Mechanical Properties of the food-can iron Samples		
	Density (g·cm-3)	σ_b (MPa)	ψ_k (%)
1	7.13	270	3.3
2	7.22	314	3.1
3	7.42	327	2.9

Microstructure of food-can iron powder metallurgy in the early stage is showed as Fig. 3. It is clearly that cracks of the samples don't pass through grain, but propagate along grain boundary. With increasing loads crack width of the samples increases, but the grain size of samples does not change. The results display that defects of grain boundary of food-can iron powder metallurgy have effects on fracture of the materials.

The propagation rate of crack of three samples rises continuously with the propagation length of crack increasing accordingly showed as Fig. 4. NO.1 sample is no damage, but NO.2 and NO.3 are damage.

The propagation rate of crack of NO.1 sample increases as crack width increasing from 0 to 1425. The propagation rate of NO.2 and NO.3 is faster than NO.1 and that results show that the propagation rate of sample with damage is faster than that of sample without damage and propagation rate increases along with the depth of prefabricated gap. About type 1 crack, formula of propagation rate is:

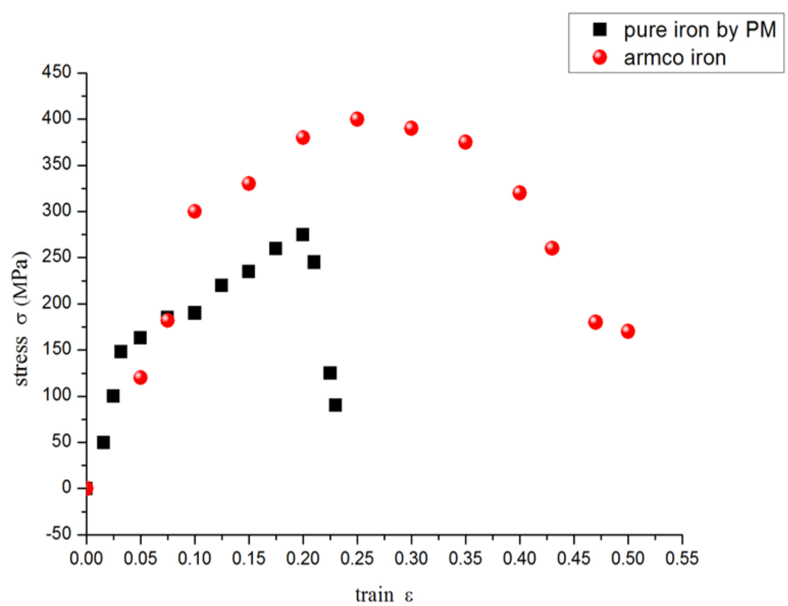

Fig. 2: Stress-strain curve of the samples

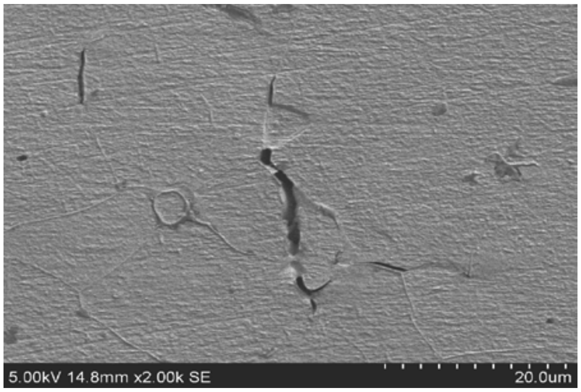

Fig. 3: Microstructure of food-can iron powder metallurgy in the early stage

$$\dot{a} = \sqrt{\frac{2\pi}{k}}\sqrt{\frac{E}{\rho}}C_0\left(1-\frac{a_0}{a}\right)$$

where, K, E, ρ, C0 are real constants of materials:

The fracture toughness data are showed as Fig. 5. It is clear that the highest fracture toughness K is achieved after strain reach at 0.02. The highest fracture toughness of the sample with damage appears when strain reaches 3~3.5. It is obviously clear that fracture toughness increases with strain whether the sample with damage or not. The fracture toughness begins to increase sharply when strain reaches about 1.6 in the condition of sample without damage. Under the condition of NO.2 sample with damage, the fracture toughness starts to increase rapidly and stress intensity factor is up to threshold when strain reaches about 2.7. The fracture toughness decreases and increasing it needs more strains because of damage.

The changing of energy release rate is approximately identical with the fracture toughness is showed as Fig. 6, but the energy release rate of sample with damage is smaller than that of sample without damage. The energy release rate takes place rapid changing requiring more strains in the condition of

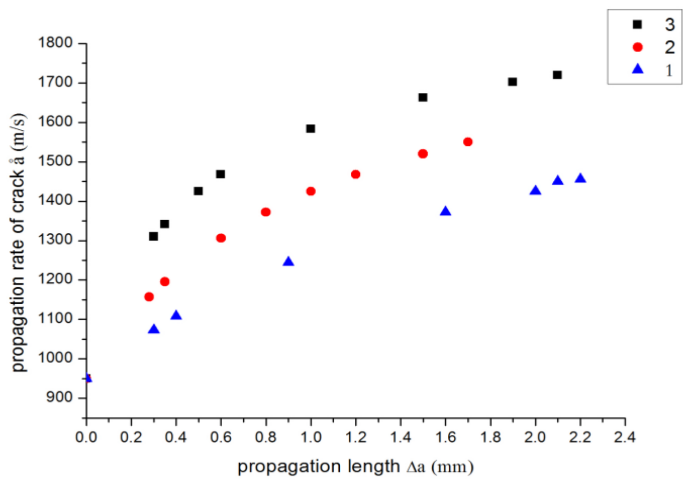

Fig. 4: The propagation rate of crack of three samples

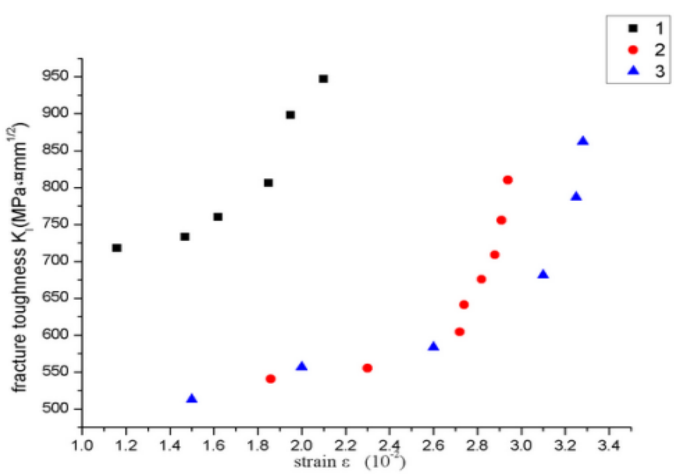

Fig. 5: The changing of fracture toughness of food-can iron powder metallurgy

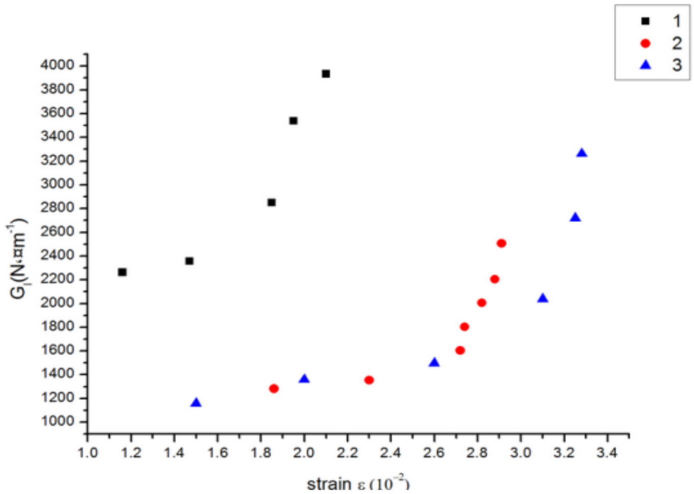

Fig. 6: The changing of energy release rate of food-can iron powder metallurgy

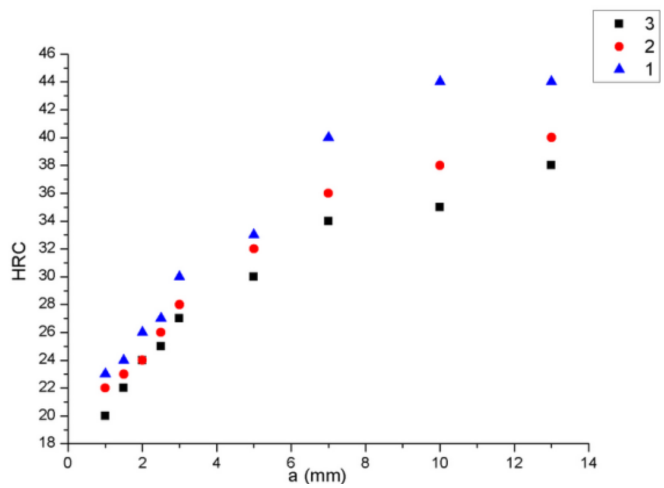

Fig. 7: The hardness of the samples for different density

sample with damage. The energy release rate of NO.2 sample with damage begins to change rapidly when strain is up to about 2.7. The changing time of NO.3 sample is later than that of NO.2 sample. This shows that the smaller the density of sample, the earlier the energy release rate begins to change. There is correspondent relationship between energy release rate and stress intensity factor and stress intensity factor is as high as energy release rate.

The surfaces of samples used in hardness tests were ground with abrasive papers (NO400-1200). Such a procedure led to the removal of a 0.5 mm thick layer to avoid the surface effecting on mechanical properties of the samples. The samples were performed with a location ranging from loading area to breaking area in order to investigate the hardness. The hardness of the samples is showed as Fig. 7.

The hardness of sample is higher in the vicinity of loading area. It is lower and value of hardness decreases evidently from 48 to 20 near breaking area. Maybe producing micro-cracks effect on the hardness and the more micro-cracks, the lower the hardness is. Greater density samples have higher hardness. The hardness of sample gradually decreases from both ends to fracture and reduction range is more obvious through loading procedure.

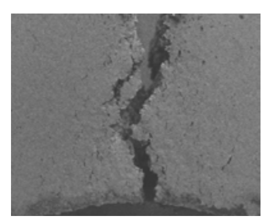

Fig. 8: The microstructure of fracture region of food-can iron powder metallurgy

In the fracture region fracture direction is perpendicular to the vertical axis from Fig. 8. In the fracture region there is no visible necking phenomenon. There are more cracks in the fracture region than anywhere else in the loading region. The hardness is higher at the loading region and hardness of the sample decreases from the loading region to the fracture region. The results show that there is little hardness in more cracks region.

CONCLUSION

- Form stress and strain figure of samples, it is clear that the changing of samples is very small form loading to end and the samples don't appear obvious buckling stage. The characteristics of samples are similar to brittle material.
- Propagation rate of sample with damage is obviously faster than that of sample without damage and increases along with depth of prefabricated gap. Increasing strain increases fracture toughness in the condition of samples with damage or not. Damage causes fracture toughness to decrease and the samples to require more strains to rapidly increase fracture toughness. The energy release rate of sample with damage is smaller than that of sample without damage and more strains can cause the energy release rate to rapidly change under the situation of sample with damage. The deeper the damage degree of sample, the earlier the energy release rate begins to mutate. There is correspondent relationship between energy release rate and stress intensity factor
- The hardness is higher at the loading region and hardness of the sample decreases from the loading region to the fracture region. The results show that there is little hardness in more cracks region and high density samples have higher hardness.

ACKNOWLEDGMENT

The authors gratefully acknowledge support from the National Natural Science Foundation of China (11262013).

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