INFLUENCE OF GRAIN SIZE AND STRAIN RATE ON ACOUSTIC EMISSION DURING DEFORMATION AND FRACTURE OF A TYPE 316 STAINLESS STEEL - PRELIMINARY RESULTS

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ABSTRACT

Effect of strain rate and grain size on Acoustic Emission (AE) behaviour during tensile deformation and fracture of an AISI austenitic type 316 stainless steel are discussed in this paper. The strain rates used in this study were in the range 2.6 x 10^{-4} to 1.04 x 10^{-1}/sec. The grain sizes used were in the range 50-200 μm. Acoustic ringdown counts generated were used for evaluating AE behaviour. Possible reasons for the non-definite nature of AE changes with strain rates and grain sizes are discussed.

KEYWORDS

Acoustic emission; austenitic stainless steel 316; grain size; strain rate; deformation; fracture; fractography.

INTRODUCTION

Acoustic Emission (AE) during tensile deformation is strongly dependent on microstructural and loading conditions. In this paper, the effects of grain size and strain rate on AE behaviour during tensile deformation and fracture in a nuclear grade AISI type 316 stainless steel are discussed.

EXPERIMENTAL

A typical analysis (in wt%) of the steel used are as follows: Ni/12.45, Cr/16.45, Mo/2.28, C/0.054, S/0.06, P/0.025. Tensile samples having gauge dimensions 32 x 6.35 x 3 mm were prepared from plates supplied in solution annealed condition (1323K for ½ hour).

Heat treatments given to the tensile specimens in vacuum better than 10^{-4} torr, for getting various grain sizes were as follows: (i) 1323K, ½ hr., Water Quench (WQ), (ii) 1423K, 1½ hr., WQ, (iii) 1523K, 1½ hr., WQ, (iv) 1623K, 1½ hr. WQ. Heat treatments (ii) to (iv) were followed by 1323K,

½ hr., WQ. The grain sizes in μm, in the respective cases were as follows: (i) 50 average (av), 55 max, (ii) 127 av, 140 max, (iii) 161 av, 240 max, (iv) 185 av, 300 max. These grain sizes measured by linear intercept method had a narrow distribution in case (i) and wider distributions in the other cases.

Some settings of the acoustic emission equipment AET-5000 system used were as follows: (i) total system gain 99dB, and (ii) threshold voltage 0.75V. Frequencies of the resonant transducers used were 375 kHz with bandpass filter 350-500 kHz, and 175 k Hz with band pass filter 125-250 kHz. A high vacuum grease was used as the acoustic couplant. Details of specimen mounting arrangements have been reported elsewhere (Baldev Raj, Jayakumar and Rodriguez 1982). Experimental conditions were optimised before the experiments so that background noises would not interfere with the results.

To study the effect of grain size, the strain rate used was $5.2\times10^{-4} s^{-1}$ and transducer frequency 175 kHz. To study the effect of strain rates, the transducer frequency was 375 kHz and strain rates used were 2.6×10^{-4}, 5.2×10^{-4}, 2.6×10^{-3}, 2.6×10^{-2} and 1.04×10^{-1} s^{-1}.

The following discussions would be based on the acoustic ring down counts (RDC). It is important to note that, another important parameter RMS voltage did not show much variation presumably due to the very low energy release during deformation in stainless steels.

RESULTS AND DISCUSSION

Effect of Strain Rate

Table 1 shows the AE behaviour during tensile testing of solution annealed specimens at different strain rates.

Table 1 Variation of ringdown counts as a function of strain rate in different strain ranges and at fracture

Strain rate (s^{-1})	Acoustic Ringdown Counts					
	Upto 2% strain	2-5% strain	5-10% strain	10% to before fracture	Total before fracture	At fracture
2.6×10^{-4}	4306	22291	688	2533	29818	5469
5.2×10^{-4}	1828	464	1099	1333	4724	24817
2.6×10^{-3}	2909	6064	38947	31835	79755	17290
2.6×10^{-2}	660	4200	1216	2495	8726	9434
1.04×10^{-1}	*	** 100	1312	7314	8571	51374

* could not be resolved; ** 0 to 5% strain

It is observed that ringdown counts in different strain ranges either increase or decrease with increase in strain rate. To understand this behaviour, we may note the factors controlling the change in extent of AE

generated with strain rate as follows: (i) increase in energy release rate with increase in strain rate, (ii) increase in mobile dislocation density with increase in strain rate, (iii) shift of frequency range of AE to higher values with increase in strain rate and strain due to decrease in time of flight for dislocations between obstacles.

Because of the last factor, the AE detected is different from the AE generated, and at different strain rates and strain values (which depend upon the above controlling factors) AE detected may increase or decrease depending on the frequency of the transducer used.

From Table 1 it is observed that the AE during first 2% of strain increased with strain rate only beyond 5.2×10^{-4} s^{-1}. But the AE during 5-10% strain range increased with strain rate even when the strain rate is below 5.2×10^{-4} s^{-1}. This behaviour might be due to the possibility that the time of flight for dislocations between obstacles may be comparable under the following two conditions.

a) At higher strain rates and when the dislocation mean free path is higher during first 2% of strain;

b) At lower strain rates and when the dislocation mean free path is lower during 5-10% strain.

The AE at fracture also either increased or decreased with strain rate. The processes which give AE during fracture are:

a) Separation of dimpled surfaces at various locations, and

b) Shearing of the area once the stress level exceeds fracture stress.

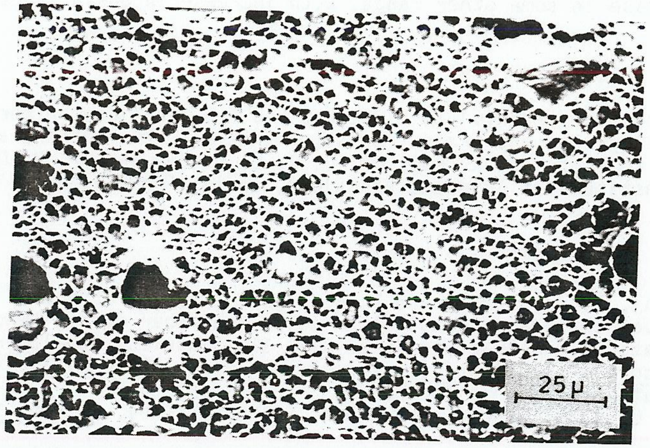
The fracture surfaces of the specimen tested at different strain rates were observed using SEM and it was found that, as strain rate increases, the dimple size increases, the total area of dimples decreases and the total area of shear increases. Figs. 1 (a) and 1 (b) give the SEM fractographs for specimens tested at 5.2×10^{-4} s^{-1} and 1.04×10^{-1} s^{-1} strain rates respectively. No shearing is seen in the former whereas a large amount of shearing is seen in the latter. Also, dimple size is higher in the latter.

Since there are two processes (responsible for AE) taking place simultaneously, as indicated above, and each giving emissions differently, the variations in ringdown counts did not have an obvious trend. However, it is more or less clear that the ringdown counts generated in the specimen tested at the highest strain rate were maximum because of the presence of the higher amount of shear areas. It may therefore be inferred that shearing process could have more influence on AE as compared to separation of dimple surfaces.

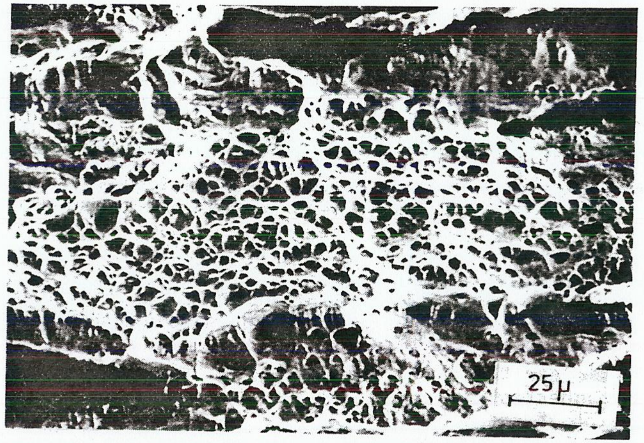
Effect of Grain Size

Table 2 gives the results of AE behaviour during tensile testing or specimens having different grain sizes. Fig. 2 gives the variation of ringdown counts with grain size in different strain ranges and at fracture.

The ringdown counts generated during different strain ranges and at fracture increased with increase in grain size except in the grain size range



(a) at strain rate 5.2 x 10^{-4}/sec.



(b) at strain rate 1.04 x 10^{-1}/sec.

Fig. 1 SEM fractographs of nuclear grade austenitic stainless steel type 316 tensile specimens.

Tensile properties				
Maximum grain size (μm)	Yield strength (MPa)	Ultimate tensile strength (MPa)	%Elongation total	uniform
55	246	572	66.0	59.5
140	218	547	65.5	58.0
240	212	539	62.0	55.5
300	206	531	66.5	58.5

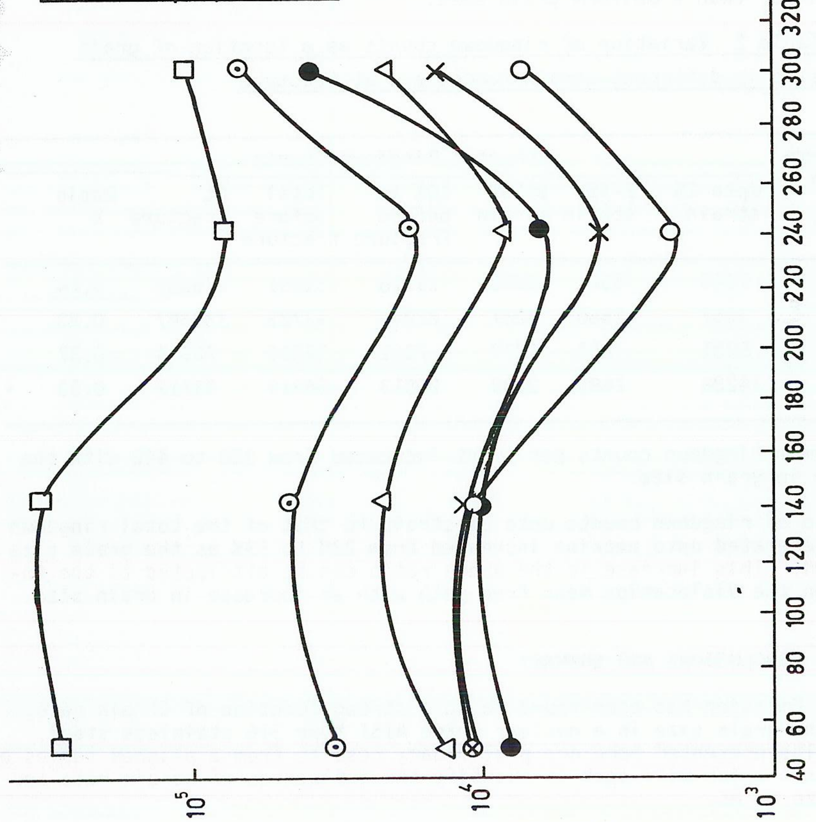


Fig. 2 Variation of ringdown counts with grain size during different strain ranges and at fracture

140-240 μm where they decreased. In the reported literature (Gereberich and Vallabhula 1980), various modes of dependencies of AE on grain sizes have been proposed for aluminium and its alloys. In these, AE have been shown to depend on one of the following: 1/d, $(1/d)^{3/2}$, $(1/d)^2$ and d, where d is the average grain diameter. In one study, (Bill, Frederick and Felbeck 1979), it has been predicted that, at the same trigger level, a decrease in grain size would produce fewer detectable events and at least for relatively fine grains, AE would be proportional to the grain diameter. On the other hand, in another study (Kim and Kish 1979), it has been predicted that only grain boundary sources for dislocation emission are considered to be responsible for AE and therefore AE would decrease with increase in grain size. It is also known (Wadley, Scruby and Speake 1980) that with increase in grain size, mean free path for dislocations between obstacles increases and therefore AE should increase. In addition to the above complicated picture, a shift in frequency range of AE is encountered with an increase in grain size (Gereberich and Vallabhula 1980). All these factors would complicate the grain size dependency on AE behaviour, particularly when a resonant type of transducer is used and when there is a distribution of sizes rather than a uniform grain size.

Table 2 Variation of ringdown counts as a function of grain size in different strain ranges and at fracture

Maximum grain size (μm)	Acoustic Ringdown Counts						
	Upto 2% strain	2-5% strain	5=10% strain	10% to before fracture	Total before fracture	At fracture	Ratio X
50	7749	5571	5055	13218	31691	275932	0.24
140	9652	2560	8287	22224	42723	332347	0.23
240	5881	814	1279	7891	16065	76994	0.37
300	34228	7489	2389	20813	64919	93712	0.53

The maximum ringdown counts per event increased from 300 to 440 with the increase in grain size.

The ratio of ringdown counts upto 2% strain to that of the total ringdown counts generated upto necking increased from 23% to 53% as the grain size increased. This increase in the above ratio can be attributed to the increase in the dislocation mean free path with an increase in grain size.

CONCLUSIONS AND SUMMARY

Acoustic Emission has been found to be a strong function of strain rate, strain and grain size in a nuclear grade AISI type 316 stainless steel. The results presented here are preliminary results from a planned series of experiments which will seek to quantify the influences of strain rate and grain size on AE.

The relationships of ringdown counts (RDC) with the above factors have been found to be complex. Thus RDC was found to (a) fluctuate with strain rate at various strain ranges, and (b) to increase in some range of grain size and decrease in some other range, with increase in grain sizes.

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