NON-DESTRUCTIVE CHARACTERISATION
BY MEANS OF ULTRASONICS
OF RADIAL CRACKS RESULTING
FROM VICKERS INDENTATIONS
IN REACTION-BONDED SILICON NITRIDE
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1. INTRODUCTION

Engineering ceramics, such as silicon nitride and silicon carbide, have a number of properties that make them very interesting as compared to metals. Among these properties the most important are: wear resistance, conservation of mechanical strength up to high temperatures and reduced weight (1-3). The main disadvantage of engineering ceramics is their brittle nature. Consequently mechanical properties show a wide variability and failure is generally caused by small flaws such as microcracks, voids, impurities and oversized grains (4-6). The critical flaw size in ceramics varies between 50 and 500 \( \mu m \) (7). Ideally, the detection limit should be around 10 \( \mu m \) or lower (8, 13). The need to detect such small defects explains why quality control of ceramics by means of non-destructive evaluation techniques is indispensable but also why many problems are still unsolved.

In the literature (9-13) the technique of ultrasonics is often mentioned as one of the most promising non-destructive evaluation methods for ceramics. In this report we will discuss the detection and sizing of radial cracks resulting from Vickers indentations in a Reaction-Bonded Silicon Nitride (RBSN) by means of ultrasonics at relatively low frequencies (20 - 30 MHz). This will allow us to evaluate the possibilities of ultrasonics in general and of our actual ultrasonic equipment more specifically. At the same time, it will show us the limitations of our system and the necessary improvements to be performed.

2. EXPERIMENTAL

2.1. Material

The material used for our experiments is a commercially available RBSN. It is fabricated by carefully nitriding silicon. As compared to other grades of silicon nitride, RBSN is quite porous. Its main advantage is that there occurs almost no shrinkage during nitriding. So it is possible to produce complex components, requiring no or only little subsequent machining (14).

2.2. Defects

2.2.1. Crack pattern resulting from a Vickers indentation in ceramics (15-21)

When a Vickers indentation is made on the surface of a brittle material a plastic deformed zone is built up under the indenter. If the indentation load
exceeds a critical value a crack pattern is developed. This crack pattern normally consists of two half elliptical surface cracks, parallel to the indentation diagonals and normally referred to as radial cracks. During unloading of the indenter the radial cracks grow to their final length and a second crack pattern is generated. These so-called lateral cracks spread outwards from the deformation zone, beneath the indentation surface and may interact with the radial system. They are approximately parallel to the specimen surface. In severely loaded specimens, they turn upwards to intersect the surface, thereby causing severe disruption of the pattern by chipping. Only loads below the chipping threshold will be considered. Figure 1 shows a schematic diagram of these crack patterns. In this report we will mainly focus our attention on the detection and sizing of the radial cracks. In what follows, the whole of indentation and radial cracks will be referred to as defect.

It is well known that the diameter of the Vickers indentation is a measure for the hardness of the material. The measurement of the radial crack length at the surface is also a technique widely used to calculate the fracture toughness of ceramics (22).

Fig. 1: Schematic diagram of the lateral/radial crack pattern resulting from a Vickers indentation.

2.2.2. Test bar with indentations

The RBSN test bar, the indentations are made in, is 20 mm long by 4.3 mm wide and 3.3 mm thick. Six indentations were made on the polished surface (4.3 mm x 20 mm) of the bar as represented in figure 2.

No special care was taken to have one of the two radial cracks orientated parallelly to the length of the test bar. Fig. 3 shows a typical optical micrograph of an indentation and the radial cracks visible at the surface in RBSN.
Table 1 summarizes the most interesting characteristics of each defect. The diagonal of the indentation and the radial crack length are measured by means of optical microscopy. The pyramid indentation depth can be estimated since the Vickers diamond has a fixed geometry. The angle made at the bottom of the indentation is 136 degrees. Ignoring elastic recovery effects, the indentation depth is 0.20 times the diagonal. The penetration depth of the radial crack is more difficult to estimate. In a first approximation we can assume that the maximum depth of the radial crack is about half the value of its length at the surface (18,21).

In the future, however, it will be necessary to measure by destructive means the penetration depth of the radial cracks of the RBSN studied.
Table 1: Vickers loads used and corresponding indentation diameter and radial crack size.

<table>
<thead>
<tr>
<th>Load P (N)</th>
<th>Indentation Diameter (10^{-6} m)</th>
<th>Indentation Maximum Depth * (10^{-6} m)</th>
<th>Radial Crack Length (10^{-6} m)</th>
<th>Radial Crack Maximum Depth * (10^{-6} m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>200</td>
<td>40</td>
<td>600</td>
<td>300</td>
</tr>
<tr>
<td>200</td>
<td>160</td>
<td>32</td>
<td>430</td>
<td>215</td>
</tr>
<tr>
<td>100</td>
<td>110</td>
<td>23</td>
<td>255</td>
<td>130</td>
</tr>
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<td>50</td>
<td>80</td>
<td>16</td>
<td>175</td>
<td>85</td>
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<td>30</td>
<td>60</td>
<td>12</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>10</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

* calculated

2.3. Ultrasonic Methods

2.3.1. Propagation velocity of ultrasonic waves

Time of flight measurements are performed in echo mode to determine the propagation velocity of the ultrasonic waves in the material. Direct-contact transducers are used for both compression and shear waves. The nominal frequency of the transducer used is 5 MHz for the shear waves and 10 MHz for the compression waves.

The ultrasonic time-delay between the first and the second back wall echo is measured using a digital oscilloscope. The measurement of the propagation velocities of the ultrasonic waves in the material allows to calculate correctly the angles of incidence for the wanted refraction angles (45° for shear waves, and 90° for surface waves, see fig. 5).

2.3.2. C-scan recording

Figure 4 shows schematically for normal incidence how the C-scans are recorded. A specimen with flat parallel surfaces is immersed in water. A focalizing transducer excited by an electrical pulse is used to send an ultrasonic wave to the specimen. After propagation in water this wave is partly reflected by the front wall of the specimen. The transmitted part of the wave propagates in the material and is on its turn reflected by the back wall of the specimen and also by possibly present flaws within the specimen. The transducer
Fig. 4: Principle of C-scan recording. The A-scan is only given for illustrative purposes as the ratio of the amplitudes is not correct. The A-scan represented is typical for normal incidence.
receives the echoes which after amplification are visualised on a digital oscilloscope (A-scan). Echoes returning from points farther from the transducer are farther to the right on the time trace. Echoes are selected by an adjustable time gate, at a time of flight corresponding with a plane within the specimen. The gated signal is digitalized and its peak to peak amplitude is stored. In order to reduce the electrical noise, the digitalized signal is averaged before the determination of its peak to peak amplitude.

A computer controlled step motor allows to move the transducer in an X-Y plane parallel to the surface of the specimen. The scanning path followed by the transducer consists of parallel lines. In this way a grid is built up, in each point of which the peak to peak amplitude is acquired as described above. With this grid corresponds hence a matrix of amplitudes. The representation of this matrix, in either two or three dimensions, is usually called a C-scan. This matrix of amplitudes also allows further data treatment. The minimal step between two points is 10 μm and the maximum surface which can be scanned with our equipment is 100 mm x 100 mm.

The situation for refracted shear waves and surface waves is somewhat different but the explained principle of C-scan recording is the same.

2.3.3. Three ways to obtain C-scans

Three different ways to obtain C-scans were studied. They are represented schematically in figure 5. In all three cases a focalising transducer is used.

Normal incidence implies that no significant refraction occurs, as can be seen in fig. 5. For normal incidence the compression waves are preponderant with respect to the shear waves in materials, having low acoustic propagation velocities such as e.g. metals. In ceramics, which have relatively high acoustic propagation velocities, also the shear waves have sufficient energy to be used, at least when working with a transducer with a sufficiently large aperture angle. Indeed, shear waves are generated in the material mostly by the outer part of the beam. As compared to compression waves, they focalize deeper, have a shorter wave length and contain more energy. The main problem, however, is to be able to distinguish between the echoes of the shear and compression waves. Normal incidence is normally used to detect internal defects.

The second method consists of using shear waves refracted as a certain angle at the interface between water and the specimen. The refraction angles more
1. compression and shear waves (normal incidence)

2. shear waves

angle of incidence

refracted shear wave

left under corner

refraction angle

3. surface waves

left upper corner

Fig. 5: Three different ways to obtain C-scans.

frequently used are 45°, 60° and 70°. We used a refraction angle of 45°. In this case, the left under corner of the specimen and the defects give rise to the echoes of interest (see fig. 5). The radial cracks can only be detected with this method when positioned at the back of the specimen.

Finally the third method makes use of surface waves obtained by inclining the transducer in water at an angle equal to or somewhat larger than the second critical angle in order to obtain a refraction angle of 90° for the shear waves. The penetration depth of these surface waves is approximately one wave length. It is obvious that this method allows only to detect surface defects and the
radial cracks have thus to be positioned at the front wall of the specimen. Remark that in this case also the left upper corner gives rise to an echo (see fig. 5).

The amplitudes of the echoes of the respective corners are used to normalize the amplitudes of the echoes of the radial cracks. It is important to emphasize that for each method the test bar and hence the radial cracks have to be positioned differently with respect to the transducer (as indicated in figure 5).

2.3.4. Ultrasonic transducer

A focalising polyvinylidifluoride transducer (Manufacturer: Ultrasonic Sciences, diameter: 3 mm) is used. Its nominal frequency and its nominal focal length as given by the manufacturer are respectively 30 MHz and 20 mm. As we have to do with a broadband transducer the actual frequency (i.e. the central frequency of the spectrum of the echo), depends on the exact configuration of the equipment and the type of waves used. In our case the frequencies for surface waves and 45° shear waves are 33 and 25 MHz respectively.

The focal spot size of the transducer (water, compression waves) was measured, using a wire of 25 μm as a reflector in water. It was found to vary between 250 and 300 μm (by rotating the specimen 90°). This corresponds well with the theoretical value of 250 μm. The focal length corresponds with the distance between transducer and specimen giving rise to the largest front wall echo in normal incidence. It appeared that the focal length of the transducer in water was 15.5 mm and not 20 mm.

2.3.5. Detection and sizing of cracks

With ultrasonics it is not possible to detect cracks orientated parallelly to the ultrasonic beam. Only cracks whose orientation is orthogonal to the incident ultrasonic beam are well detected. So in a single C-scan we can detect only one of the two radial cracks of each indentation. The right orientation is obtained experimentally by rotating the specimen in such a way as to obtain the maximal amplitude of the echo. The other radial crack can only be detected by rotating the specimen 90° (in so far as the dimensions of the specimen allow this of course).

When the focal spot of the ultrasonic beam is smaller than the crack, this last one can be sized by measuring the distance between the points corresponding with the amplitudes at -6 dB of the echo and this with respect to the
maximum amplitude of the echo. If, however, the focal spot size is larger than the dimension of the crack, then the previous method will always yield the size of the focal spot itself (in so far as the signal reflected by the crack is large enough). In this case, one can only say that the crack is equal or smaller than the focal spot size. A useful parameter might then be the maximal amplitude of the echo. This amplitude depends, amongst other things (such as angle of incidence, surface roughness,...), on the reflective crack surface and if well calibrated, preferably with reference defects, it can be used for sizing.

3. RESULTS AND DISCUSSION

3.1. Propagation velocity of ultrasonic waves

The velocity of the compression and shear waves is $10800 \text{ m/s} \pm 400$ and $6030 \text{ m/s} \pm 30$ respectively. The velocity of the surface waves is about equal to that of the shear waves. Using Snell's law, this allows to calculate that the angle of incidence in water has to be around $14^\circ$ to obtain surface waves; $45^\circ$ shear waves are obtained by inclining the transducer at an angle of $11^\circ$ in water.

3.2. C-scan recording

3.2.1. Normal Incidence

It was not possible to detect any of the radial cracks in normal incidence (normal with respect to the plane containing the radial cracks). This can be attributed to the fact that for the radial cracks the transducer has to be positioned at the edge of the specimen, making the interpretation of the obtained signals very difficult. Remark that normally for internal flaws and cracks orientated parallelly to the surface the method of normal incidence is very useful.

3.2.2. Surface Waves

Fig. 6 shows a C-scan obtained by means of surface waves, represented in three dimensions, of an area of $12.5 \text{ mm} \times 5.5 \text{ mm}$, containing all six defects. The arrows indicate the peaks corresponding with the defects.

The four biggest defects can be distinguished easily. The fifth and especially the sixth and smallest one, however, are only barely visible. Remark that the amplitudes of the echoes due to the fifth and sixth defect have the same order of magnitude as those of the small echoes at the surface of the specimen, whose origin has not been investigated yet.
Fig. 6: C-scan, represented in 3 dimensions, of a surface of 12.5 mm x 5.5 mm, obtained by means of surface waves (step 50 μm).

Fig. 7 shows the C-scans of each defect. The gate was chosen in such a way as to detect at all positions of the transducer the peak to peak amplitude of the echo of the defect. The colours represent intervals of amplitude levels, calculated in dB and this with respect to the maximum amplitude of the echo caused by the surface waves. This maximum does not necessarily correspond with the maximum of the represented C-scans. The white vertical straight line represents the crack length obtained by the -6 dB drop of the amplitude (see further 3.4.1.). The two biggest defects give rise to quite a strange C-scan, showing three maxima. For the four smallest defects two maxima are observed.

The C-scans obtained for the first and the second defect can be interpreted as follows. The first maximum (on the left in the C-scans) is probably due to a direct reflection in water of the incident ultrasonic beam by the indentation. The two other maxima, which have an elongated shape, are most probably due to reflection of the surface waves by the radial crack. The elongated shape of these two maxima is a further confirmation that we have to do with surface waves.

A mathematical modelling of this experimental situation is possible and will be performed.
Fig. 7.a: C-scans of defects n° 1, 2, 3 (step 10 μm) obtained with surface waves. Levels in dB are calculated with respect to the maximum amplitude of the echo of the surface waves, which does not necessarily correspond with the maximum amplitude of the respective C-scans.
Fig. 7.b: C-scans of defects n° 4, 5, 6 (step 10 μm) obtained with surface waves. Levels in dB are calculated as for defects n° 1, 2 and 3.
Around the indentation the surface waves are reflected by the indentation itself as illustrated in fig. 8. This diminishes the reflection of the surface waves in such a way as to hide the central part of the radial crack, explaining the occurrence of the two maxima for the surface waves.

These two maxima are not situated symmetrically with respect to the first maximum, and one of the two has a somewhat lower value. This is due to the fact that the radial cracks detected are not always orientated completely orthogonally to the incident ultrasonic beam (i.e. along the Y-axis, see fig. 6). Furthermore, as can also be observed in fig. 3, the two ends of the radial crack are not always situated in the same plane.

![Diagram showing scattered surface waves](image.png)

**Fig. 8: Scattering of the surface waves around the Vickers indentation.**

Two maxima are detected for the four smallest defects. The first maximum (on the left in the C-scans) can again be attributed to reflection of the incident ultrasonic beam in water by the indentation, whereas the second maximum is most probably caused by the reflection of the surface waves by the radial crack. The fact that only one maximum is detected for the surface waves can be ascribed to the small dimensions of the radial crack as compared to the focal spot size, making it impossible to distinguish between the two ends of the radial crack. Remark that the radial cracks along the X-axis are not detected (see fig. 6).

Fig. 9 illustrates the difficulties to detect the radial cracks. It shows three C-scans of the third defect, in each of which the defect has a slightly different orientation with respect to the incident ultrasonic beam. Whereas the indentation is well detected for all three orientations (maximum on the left),
Fig. 9: Influence on C-scanning of the orientation of the radial crack with respect to the incident ultrasonic beam (surface waves). The levels in dB are calculated with respect to the maximum amplitude of the respective C-scans (third defect).
this is not the case for the radial crack. When the radial crack is not well orientated as in the first C-scan of fig. 9 almost no reflection of the surface waves occurs and no distinct second maximum (on the right) is observed. The third C-scan illustrates the good orientation (crack more or less orthogonal to ultrasonic beam), whereas the second illustrates an intermediate case. The orientation of the radial crack with respect to the incident ultrasonic beam is clearly a very important parameter.

3.2.3. Shear Waves inclined at 45°

Fig. 10 shows a C-scan represented in three dimensions, obtained by means of 45° shear waves. The arrows again indicate the peaks corresponding with the defects. Due to the rather small focal distance of the transducer it was not possible to focalise on the back wall. The focalising plane is situated about 0.5 mm above the back wall (see fig. 4 and 5).

The three largest defects can be distinguished quite easily. The fourth and especially the fifth are only barely visible, whereas the smallest one of 100 µm was not detected at all. Remark also the existence of at least five other small echoes, whose amplitude has the same order of magnitude as that of the echo caused by the fifth defect. Their origin has not been investigated yet.

Fig. 10: C-scan represented in three dimensions of a surface of 13.5 mm x 3.5 mm, obtained by means of shear waves (step 50 µm).
Fig. 11.a: C-scans of defects n° 1 and 2 obtained by means of shear waves inclined at 45° (step 10 µm). The levels in dB are calculated with respect to the maximum amplitude of the respective C-scans.
Fig. 11.b: C-scans of defects n° 3 and 4 obtained by means of shear waves inclined at 45° (step 10 µm). The levels in dB are calculated with respect to the maximum amplitude of the respective C-scans.
Fig. 11 shows the C-scans of each defect. The C-scans of the two biggest defects show two maxima, whereas for the smaller ones only one maximum is detected. The vertical white straight line on the C-scans represents the crack length obtained by the -6 dB drop of the amplitude (see further 3.4.1.). The detected maxima are most probably due to reflection of the shear waves by the radial cracks. Indeed, the intensity of the incident wave on the indentation and on the radial crack is equal, whereas in the previous case of surface waves, the intensity of the compression wave incident on the indentation in water is much larger than the intensity of the surface wave incident on the crack. This difference in intensity can be accounted for by the transmission between water and ceramic and explains why no maximum is observed due to the indentation.

The fact that two maxima are observed for the biggest cracks can again be attributed to scattering of the shear waves by the indentation. The other radial cracks are too small with respect to the focal spot in order to be able to distinguish between the two ends of the radial crack. That is why only one maximum is detected. Remark that again only the radial cracks, more or less orientated along the Y-axis, are detected (see fig. 10).

3.3. Lateral cracks

A point which shall be examined in greater detail is whether the lateral cracks can be detected. Therefore, the specimen should have a different position with respect to the transducer from the ones we have studied so far. Remark that in the case of 45° shear waves the lateral cracks can have a similar effect on the image as the indentation.

3.4. Sizing

3.4.1. -6 dB method

Table 2 summarizes the results of dimensioning by means of the -6 dB drop of the amplitude as explained before. Remark that on the C-scans sizing of the radial cracks can be performed only along the Y-axis (see fig. 6 and 10). Only the two largest radial cracks can be dimensioned properly by means of the -6 dB method, as their dimensions are bigger than the focal spot size. The maximum error for crack 1 and 2, as compared to the dimensions obtained optically, is about 20%. This result can be considered to be reasonably good.

The third crack is a limit case, as its size is about equal to that of the focal spot. With shear waves it is well sized whereas with surface waves it is
Table 2:  Sizing of the radial cracks by means of the method of the -6 dB amplitude drop.

<table>
<thead>
<tr>
<th>Crack</th>
<th>Crack lengths as measured by optical microscopy (10^-6 m)</th>
<th>Sizes obtained by shear waves (10^-6 m)</th>
<th>Sizes obtained by surface waves (10^-6 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>600</td>
<td>570</td>
<td>490</td>
</tr>
<tr>
<td>2</td>
<td>430</td>
<td>490</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>255</td>
<td>240</td>
<td>330</td>
</tr>
<tr>
<td>4</td>
<td>175</td>
<td>250</td>
<td>310</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>n.m.</td>
<td>340</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>n.d.</td>
<td>220</td>
</tr>
</tbody>
</table>

n.m. = not measured  
n.d. = not detected

oversized. This is due to the fact that the focal spot size of the surface waves (~ 320 μm) is somewhat larger than that of the shear waves (~ 250 μm), as can be ascertained from table 2. Indeed for cracks smaller than the focal spot size a size of 250 μm is obtained when using shear waves, whereas by means of surface waves a value of 330 μm is measured.

The cracks (n° 4, 5 and 6) smaller than the focal spot are oversized (in so far as they are detected). In that case the size of the focal spot itself is measured. The -6 dB length, as measured with surface waves, of the 6th crack is only 220 μm, where one would normally expect 320 μm (focal spot size). This can be attributed to the fact that the detection limit was reached, bringing about quite some noise as can be observed in the 3th C-scan of fig. 7b.

3.4.2. Relationship maximum amplitude and surface of crack

We have tried to correlate the maximum amplitude of the echo with the reflective surface of the crack. This surface can be approximated by half a circle, having as diameter the radial crack length measured at the surface.

In table 3 we have grouped the maximum amplitudes of the echo for both shear and surface waves, the calculated reflective surface and the radial crack length measured optically. The amplitudes have been normalized with respect to the amplitudes of the echoes of the respective corners.
Table 3: Maximum amplitude of the echo for both shear and surface waves and the corresponding reflective surface and length of the radial crack.

<table>
<thead>
<tr>
<th>crack</th>
<th>crack length $(10^{-6} \text{m})$</th>
<th>reflective surface $(10^{-9} \text{m}^2)$</th>
<th>max. amplitude* shear waves $(\text{V/V})$</th>
<th>max. amplitude* surface waves $(\text{V/V})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>data set 1</td>
<td>data set 2</td>
</tr>
<tr>
<td>1</td>
<td>600</td>
<td>141</td>
<td>0.223</td>
<td>0.244</td>
</tr>
<tr>
<td>2</td>
<td>430</td>
<td>73</td>
<td>0.219</td>
<td>0.166</td>
</tr>
<tr>
<td>3</td>
<td>255</td>
<td>26</td>
<td>0.094</td>
<td>0.061</td>
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<tr>
<td>4</td>
<td>175</td>
<td>12</td>
<td>0.032</td>
<td>0.030</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* normalized with respect to echo of corner

For the shear waves two data sets are presented. These were obtained by repeating twice the measurements, starting the experiment each time from scratch.

As can be ascertained from fig. 12, the variation of the reflective surface of the crack with respect to the maximum amplitude of the echo can be exploited to size the radial cracks. A much larger number of cracks, however, should be studied in order to better define this relationship and to know exactly within which limits it is valid. The most important parameters are the crack geometry, the material studied and the ultrasonic equipment used.

It is not completely clear why data set 1 and data set 2 obtained by shear waves yield results which differ by up to 50%. A possible explanation might be a different orientation during acquisition of the two data sets. Furthermore, one should remember that the dimensions of the radial crack depend quadratically on the normalized amplitude. This implies that an error of 50% on the amplitude represents an error of "only" 20% on the crack size.

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crack surface as a function of norm.max.amplitude of echo surface waves

Fig. 12: Crack surface as a function of maximum amplitude of the echo for both surface and shear waves.

3.5. Comparison with the literature

We are not aware of the existence of any literature on the detection and sizing of radial cracks by means of ultrasonics at 30 MHz. Fatkin et al. (23) report on the visualisation of the indentation and the radial cracks by means of Scanning Acoustic Microscopy (SAM) at frequencies varying between 200 and 300 MHz. They also claim to be able to visualize the lateral cracks. A. Dussoulier (12) mentions the technique of dye penetrants. Radial cracks of 40 μm in SiC are reported to be detected.
4. CONCLUSIONS

Radial cracks resulting from Vickers indentations have been examined by means of ultrasonics at a frequency of around 30 MHz. The sizes of the radial cracks varied between 100 and 800 μm. Surface waves allowed to detect all radial cracks whereas shear waves inclined at 45° did not allow to detect the smallest radial crack of 100 μm. The presence of the indentation complicates quite the interpretation of the images obtained.

The method of the -6 dB amplitude drop allows to size radial cracks down to 250 μm. The frequency used (in our case 30 MHz) determines this limit. The relationship between maximum amplitude and reflective surface can also be useful for sizing. A much larger number of cracks should be studied to better define this relationship.

The obtained results are quite encouraging. It has been shown that ultrasonics are a useful tool to detect and to size cracks in ceramics. However, the limits of our existing equipment have been reached. If we want to decrease the detection limit of 100 μm and the sizing limit of 250 μm it is necessary to increase the frequency. This implies the purchase of a high-frequency equipment up to 150 MHz. Furthermore, it is also indispensable to dispose of a better displacement mechanism with more grades of freedom in order to position and rotate more accurately the specimen with respect to the transducer.

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Ultrasonics are one of the most promising techniques for the non-destructive testing of engineering ceramics, especially for the characterisation of cracks. In this article the detection and sizing of radial cracks resulting from Vickers indentations in Reaction-Bonded Silicon Nitride (RBSN) by means of ultrasonics at relatively low frequencies (30 MHz) are discussed. The crack lengths varied between 100 μm and 600 μm. Bulk shear waves and surface waves are used to obtain the C-scans. The interpretation of the images obtained is complicated by the presence of the indentation. Two methods to size the radial cracks are used: the -6 dB amplitude drop and the relationship between maximum amplitude of the echo and the reflective crack surface. The results obtained are discussed and compared with the sizes measured by optical microscopy.