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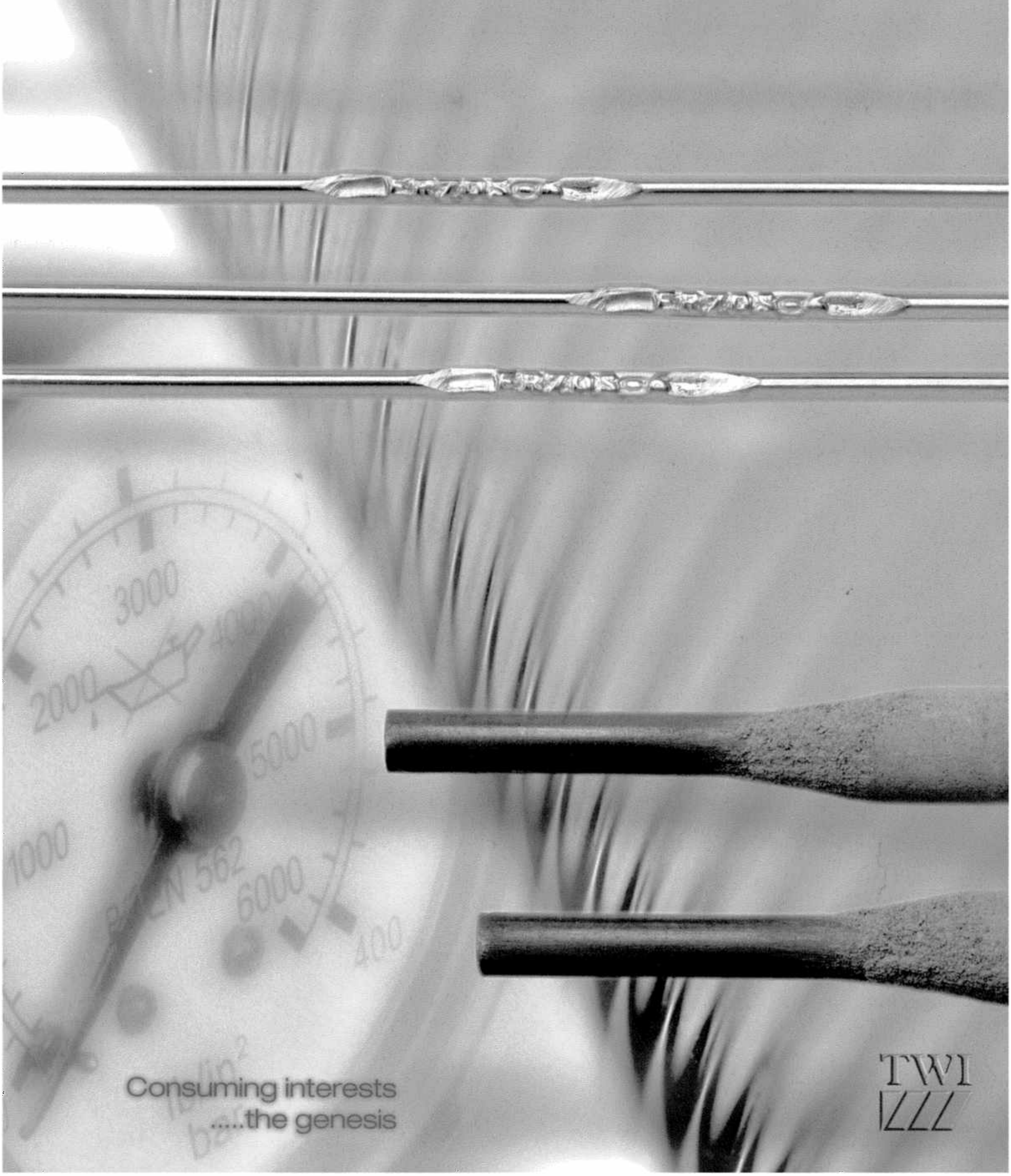


Consuming interests
.....the genesis

TWI

Piezoelectric transducers adopted for storage tank monitoring .... the results

Microscopic structural vibrations lead the way.

The last edition of the *Bulletin* introduced an experiment to explore the possibility of using piezoelectric transducers both to generate and measure the modal properties of a model storage tank wall. It offers the potential for near 100% condition monitoring of real tank walls and potentially other large engineering structures. Here, author *Stephen Williams* concludes his work with the results of that experiment.

Stephen Williams joined TWI in 2001 and works in the area of non-destructive testing as a senior project leader. He has been involved in various projects developing new testing techniques. Before joining TWI he did a PhD at Bristol University developing a tap test method for condition monitoring of structural steelwork. He also worked for three years at the Gillette R&D laboratories in Reading.

Repeatability of stepped frequency scans

Figure 1 and Table 1 (both reproduced from the September/October edition of *Bulletin*) summarise the experiments and illustrate the different testing configurations and tank states. The results are recorded with the actuator connected between locations two and three; experiments with the actuator connected between locations one and four showed similar results but for brevity are not presented here.

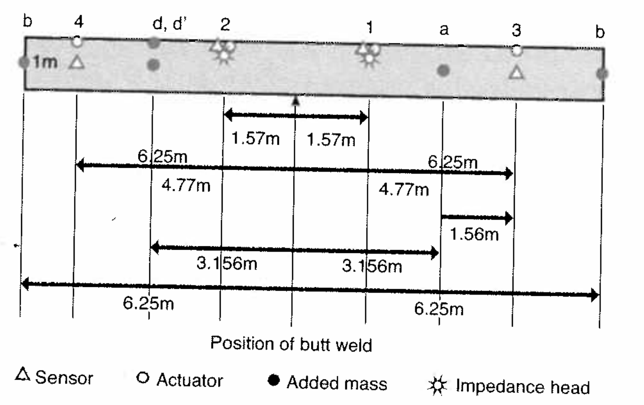


Fig.1. Tank states and testing configurations

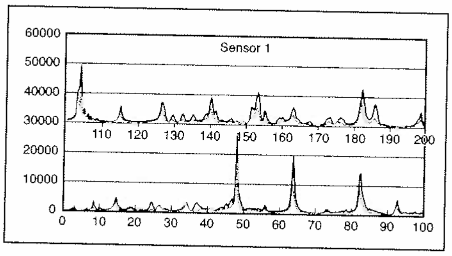
Table 1. Summary of tank wall experiments with actuator connected between location 243.

Experiment No	Tank state	Scan resolution (Hz)
1	Unmodified	0.1
2	W(a)	0.1
3	W(b)	0.1
4	W(d)	0.1
5	Unmodified	0.1
6	Unmodified	1
7	W(d')	1

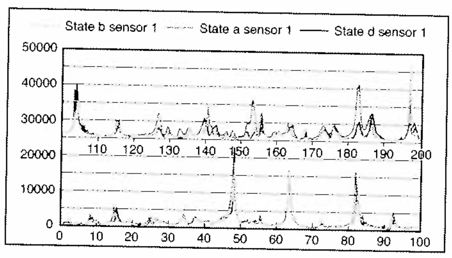
Experiment one and experiment five were repeat scans (0.1Hz step size) of the tank wall with no modification. Examples of the frequency spectra for each experiment are overlaid in Fig. 2(a) (sensor one), Fig. 3(a) (sensor two), Fig. 4(a) (sensor three) and Fig. 5(a) (sensor four).

Note that in these figures the 100Hz to 200Hz range is stacked above the 1Hz to 100Hz range with an arbitrary offset. Note also that the repeat scans were taken two weeks apart. Between the first and second experiment, the actuator cable was disassembled and then reassembled and re-tensioned. The spectra from all the sensors indicated good agreement in the relative amplitudes

Fig. 2. Tank wall spectra at sensor one for stepped frequency scan (0.1Hz step)

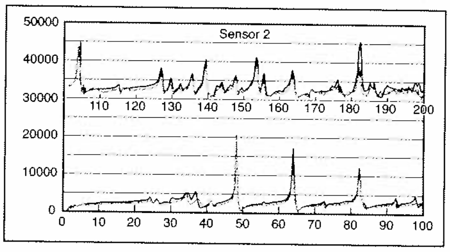


a. Repeat scans on unmodified tank (measurements taken 15 days apart)

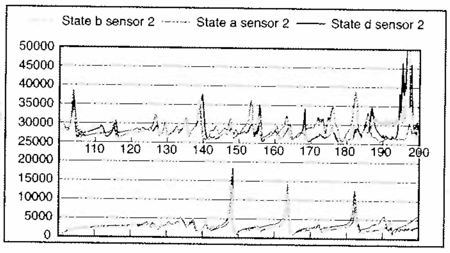


b. Scans on tank modified with 1kg added mass at a, b and d

Fig. 3. Tank wall spectra at sensor two for stepped frequency scan (0.1Hz step)

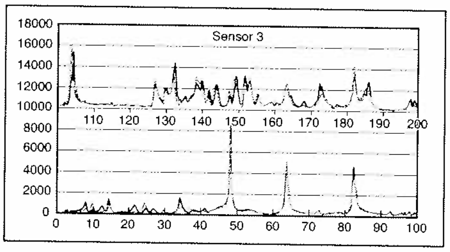


a. Repeat scans on unmodified tank (measurements taken 15 days apart)

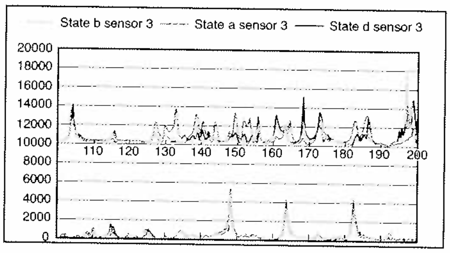


b. Scans on tank modified with 1kg added mass at a, b and d

Fig. 4. Tank wall spectra at sensor three for stepped frequency scan (0.1Hz step)

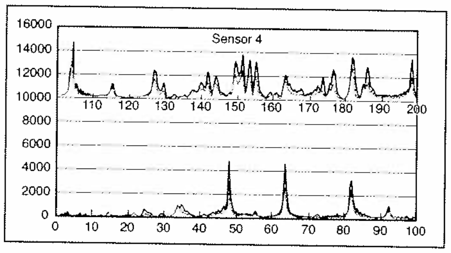


a. Repeat scans on unmodified tank (measurements taken 15 days apart)

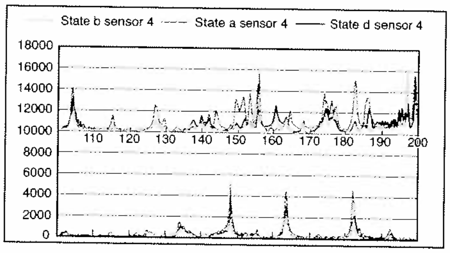


b. Scans on tank modified with 1kg added mass at a, b and d

Fig. 5. Tank wall spectra at sensor 4 for stepped frequency scan (0.1Hz step)



a. Repeat scans on unmodified tank (measurements taken 15 days apart)



b. Scans on tank modified with 1kg added mass at a, b and d

between repeat experiments.

However, an exception to this is a prominent peak appearing at 97Hz in the spectrum of sensor two for one experiment but not the other (Fig. 3(a)). This is discussed below in relation to results from the 1Hz step size scans. There did not appear to be any other difference in the repeatability between the 1-100Hz and 100-200Hz frequency ranges. The amplitudes of the spectral peaks are noticeably more variable than the frequencies, although not excessively so.

At 1Hz step size the spectra appear smoother than those with 0.1Hz step size (see Fig. 6), but with no apparent loss of important detail. This means that future applications of PD technology to tanks could be completed 10 times faster (under the experimental conditions used the 1-200Hz range could be scanned in six minutes instead of an hour). Fig. 6(a) shows the spectra of the unmodified tank scanned with 1Hz step size. These show good agreement with the scans taken 120 days earlier with 0.1Hz step size.

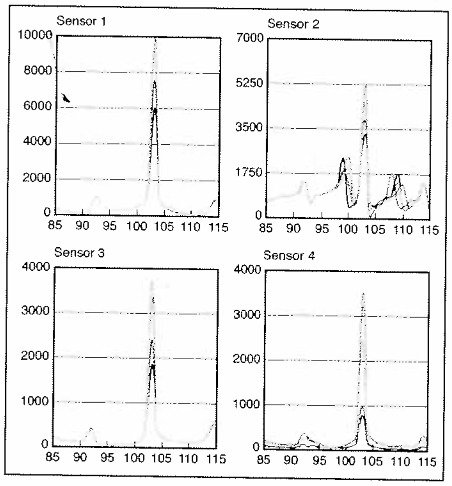
The frequency repeatability, illustrated by the proximity of the overlaid peaks along the horizontal axis, is excellent for repeat scans which were all taken on the same day.

However, the repeatability is noticeably poorer for two peaks either side of a prominent peak at 103Hz at sensor two. One of them corresponds with the peak at 97Hz which appeared on only one of the repeat scans taken with 0.1Hz step size (see Fig. 3(a)). Further experimentation is required to explain why these peaks exhibit a higher degree of variability than other peaks. Nevertheless, in general, the significance of the observed repeatability depends on how it compares with the sensitivity of the method to the added mass.

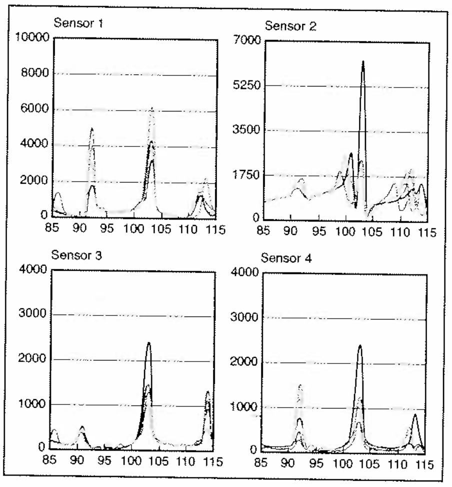
Sensitivity to added masses

Experiments two, three and four were scans of the tank wall with modification 'W(a)', 'W(b)' and 'W(d)' (corresponding to wall added masses at a, b and d) respectively. Examples of the spectra for these experiments are overlaid in Fig. 2(b) (sensor 1), Fig. 3(b) (sensor 2), Fig. 4(b) (sensor 3) and Fig. 5(b) (sensor 4). Note that in these figures the 100Hz to 200Hz range is again stacked above the 1Hz to 100Hz

Fig. 6. Tank wall spectra obtained by stepped frequency scan (1Hz step size)



a. Unmodified tank



b. Tank 0.86kg steel block attached to wall range with an arbitrary offset. Note also that in these figures modifications W(a), W(b) and W(d) are referred to as 'state a', 'state b' and 'state d' respectively. All three scans were taken over a period of one week.

The first point to note is that, below 100Hz, there is very little difference between the spectra of the tank with the mass at different locations (except that between 80Hz and 100Hz the spectrum from sensor two state 'a' (see Fig. 3(b)) differs from those of state 'd' and state 'b').

In other words there is generally no ability to discriminate between different locations of added mass below 100Hz. However, between 100Hz and 200Hz there is clearly more difference between the scans of the modified states. While the spectra of the tank wall in state 'b' and state 'd' are similar to each other, that of state 'a' differs noticeably from both of them.

In fact the spectrum of state 'a' is generally similar to that of the unmodified tank while those of the tank wall in state 'b' and state 'd' are noticeably different from it, suggesting that in states 'b' and state 'd' there was sensitivity to the added mass but that there was considerably less sensitivity in state 'a'.

The sensitivity to modifications W(b) and W(d) and the similarity between these spectra can be explained by the symmetry of the tank; the cable imposes symmetry constraints on the mode shapes. Consequently, the positions of the masses were symmetrically equivalent relative to the actuator cable between locations two and three (Fig. 1). The most dramatic indications on the spectra of the tank modified with 'W(b)' and 'W(d)' occurred near 200Hz.

This produced prominent growths in the amplitudes of the modal peak at all sensors. In the case of sensor two, the change in amplitude is very pronounced (12 times the amplitudes in the unmodified state). In fact there appear to be two modal peaks close to 200Hz and it is the lower frequency of the two which is enhanced more.

Given the symmetry considerations described above, one might expect the response to modification W(a) to be the same as that for W(b) and W(d). The results suggest that the tank was not perfectly symmetrical, perhaps due to a manufacturing irregularity. Despite this, in state a, two new peaks occur at 90Hz and at 100Hz for sensor two (one peak is interrupted at the break between the frequency ranges). Similar peaks also appear in the spectra for state 'b' and state 'd' at about 110Hz at sensor two (see Fig. 3). Despite being less dramatic than the increases near 200Hz, these indications between 90Hz and 110Hz are consistent for all of the tank states.

To confirm the sensitivity to structural change in this range of the spectrum scans between 85Hz and 115Hz, with a 1Hz step size, were conducted. A lighter 0.89kg added mass was attached at location d' (at the top of the wall). The spectra produced by these scans cannot be directly compared with those from the 0.1Hz step size scans because the size, location and method of attachment of the mass were different. However, the size and location were similar and therefore damage sensitivity comparable with that obtained with the heavier mass could be expected.

Before discussing the damage sensitivity observed with the 1Hz step size scans it should be noted that the indications that occur at 86Hz on sensor one and sensor three of the modified tank were observed on only one of the eight repeat scans. These peaks might therefore be considered spurious (Fig.6b).

Fig. 6(b) shows that the spectra of sensor one, sensor three and sensor four are noticeably changed by the presence of the added mass. The most obvious changes are in the relative modal amplitudes. The effect of the added mass on the sensor two response was much less noticeable. Less obvious than these changes in relative spectral peak amplitude, but equally important, is the slight reduction in the frequency of the spectral peaks. For example, Fig. 6 shows that at 115Hz on sensor three a peak is downshifted by the added mass by about 1Hz. Although only a small shift it is nevertheless important because of the good frequency repeatability observed at this peak. Similar frequency shifts occur at other spectral peaks.

This frequency-shift indication was not evident with the larger mass attached at half wall height and may therefore show that damage sensitivity increases the closer the structural modification is to the top of the tank.

Practicality of this method for industrial application.

There is a great need for global in-situ monitoring of storage tanks, both for the walls and floor. It is believed that the structural changes to the model tank in this experiment are comparable with changes caused by typical damage to real tank walls. Real tanks are many times larger, have structural features such as roofs, stiffeners and attachments and are usually either completely or partially filled with oil. Further development of this technique will be aimed at validating the method under these conditions. For example, tank walls may suffer from internal corrosion caused by floating roof abrasion. This removes the protective coating and causes accelerated corrosion. One of the remaining challenges is to adapt this technique for the detection of structural change on the tank floor. The fillet weld is at the centre of a small 'T' shaped zone in which corrosion is known to occur (see TWI Members report 800/2004).

Therefore maximizing the sensitivity of the test in this region would be a priority in any future development. Although the spectra of real tanks will differ from those observed in these experiments it is reasonable to assume that the observed generic behavior will be similar.

The ultimate aim is to offer a complete in-situ screening system for the whole tank. However, it is acknowledged that considerable development is needed for this promising technique.

Conclusions

It has been shown to be possible to obtain the modal properties of a model storage tank using piezoelectric transducers (PD technology).

PD technology has detected structural modifications on the wall of a model storage tank comparable with that of localised corrosion, demonstrating the potential of this method for corrosion monitoring on full sized storage tanks.

net gains

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Ceramics

The American Ceramics Society offers information about the organisation and its activities. There are tables of contents from their publication *Ceramic Bulletin*, a searchable archive of tables of contents with abstracts from *Journal of the American Ceramic Society* and details of their other publications. Fact Sheets are available on ceramics in aerospace, automobiles, electronics, medicine, consumer products, fibre optics, military applications and the environment, though they are not easy to find. Links are given to ceramic properties databases.
http://www.acers.org/

The above site also gives access to:
Ceramic Source Online which supplies details of equipment and materials used to manufacture advanced and traditional ceramics. American Ceramic Society members, paid subscribers and registered visitors may access 1,000 products and services and 2,600 vendor companies. Members and subscribers also have access to more information on companies, identifying product manufacturers, obtaining contact information for companies and product sourcing in the local area.
http://www.ceramicsource.org/

The Society of Glass Technology gives details of obtaining membership of the organisation. It also includes a conference diary, publications details and contents pages for the major journals, and a searchable index back to the early 1900s. A list of consultants is included.
http://www.societyofglasstechnology.org.uk

Institute of Materials, Minerals and Mining (IOM³), Ceramics Industry Division is a section of the IOM³ website encompassing all professional, technical and educational aspects of the broad ceramics community. It includes latest news of the Ceramics Division of IOM³; Ceramics related events; an interesting set of foresight drivers for the ceramics sector, giving the business drivers, issues and technology and innovation needs for each driver; the division's annual report and lists of members of the constituent committees of the division.
http://www.iom3.org/divisions/ceramics/index.htm

Technical Ceramics Information Centre (Informationszentrum Technische Keramik) offers basic information on events in the ceramics industry and producers of ceramics in Germany, and gives details of ceramic materials, including a classification of technical ceramics materials to ENV 12212. There seem to be two methods of accessing some information, so some time spent working around the different levels of the site, especially rapidly clicking on the coloured 'trade user information' button would pay dividends.
http://www.keramverband.de/eng/

Ceramic Industry is the online journal published by Business News Publishing Co., which describes itself as the 'global voice of ceramic manufacturing' to promote interests, growth and progress of the ceramic, glass and brick industries. It includes up-to-date coverage of news, issues and trends, and aims to offer solutions to manufacturing problems and a forum for information exchange. No registration is required to access the journal.
http://www.ceramicindustry.com/

The Ceramics Web Book is produced by the Ceramics Division of the Materials Science and Engineering Laboratory at NIST (National Institute of Standards and Technology), USA. It offers evaluated data in the form of a high-temperature superconducting materials database, a structural ceramics database and property data summaries for advanced materials; a guide to data centres, sources, tools and resources, including links to software and other resources.
http://www.ceramics.nist.gov/webbook/webbook.htm