break the covalent bonding perpendicular to (0 0 1) plane. This undoubtedly supports the existence of an easy (1 1 0) cleavage in these crystals. It may be mentioned that along both the directions the strain varied linearly with stress before the crystals broke under compression.

When an indented face was subjected to etching, considerable random cracking was observed around the indentation mark, and no rosette pattern was formed, indicating that the crystals do not undergo plastic deformation at room temperature. This view is also supported by our hardness experiments. High temperature might produce slip. The density of transparent crystals, determined by the bottle method [19] at $28°$ C, was $2.003 \, g \, ml^{-1}$. The solubility in water was found, using stoppered flasks, to be $0.0689 \, g$ per $100 \, ml$ at $28°$ C. The specific resistivity at $26°$ C was observed to be $5.3 \times 10^9 \, \Omega \, cm$.

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On the spark machining of cubic Laves-phase compounds which contain gadolinium

The cubic Laves-phase compounds of gadolinium are of interest to research workers in the fields of Mössbauer spectroscopy and nuclear magnetic resonance because the nature of the hyperfine field at the lattice sites yields information on the nature of the spin-exchange interactions in the bulk material. The gadolinium compounds which are, at present, of most interest are $GdFe_2$ and $GdCo_2$. These compounds are manufactured by melting a stoichiometric mixture of gadolinium and iron or cobalt powders in either an electron beam furnace or an argon arc furnace. Once the molten state has been reached the samples are quenched rapidly to room temperature. They are then turned over and the samples remelted. This procedure is performed several times to ensure homogeneity within the sample. Ingot sizes are usually small: typically they are produced as cylinders having diameters of about $10 \, mm$ and heights of about $4 \, mm$.

After the ingots of the compounds have been manufactured they have to be converted into the

shape which is required for the experiment; thin discs, spheres, ellipsoids or toroids, which have to be machined from the ingot. The high chemical activity of gadolinium imposes restrictions on the procedures by which samples may be prepared from the ingots. For example, gadolinium oxidizes very easily and powder specimens are usually crushed or filed in an alcohol bath to minimize the formation of Gd_2O_3. The use of high- and low-speed diamond saws is impractical, both because of the high chemical reactivity of gadolinium, and because they cannot be used to produce the shapes which are required. Diamond impregnated and chemical wire saws could be used, but wander of the wire during cutting limits the accuracy of the shapes which are to be cut. The technique which meets both the requirement that cutting should take place in a non-reactive atmosphere, and the requirement that complicated shapes can be fabricated, is that of spark-machining. This note describes the effect of spark-machining on poly-crystalline specimens of $GdFe_2$ and $GdCo_2$.

A Servomet Type SMD spark-erosion machine was used. The dielectric medium, kerosene, was recirculated through a high capacity filter unit. The cutting tool was tungsten, because of its low rate of wear during the sparking process. For the $GdFe_2$ specimens ranges 3, 5 and 7 of the spark-erosion machine were used. Range 5 only was used for the $GdCo_2$ specimens.

The distribution of erosion craters on the cut surface was investigated using a Baker metallurgical microscope fitted with an A.E.I. image-splitting eyepiece. The surfaces of the specimens are similar to others described in the literature [1]. After cutting they are covered by an isotropic distribution of craters, the diameters of which are fairly constant. The deviations from stoichiometry and gross mechanical damage arising from the sparking process have been investigated using X-ray diffraction techniques. Chemical etching was used to remove the surface layer to a depth of $5\,\mu m$, and then the surface was subjected to X-ray analysis. Etchants used were either nital (5%) or dilute nitric acid (1 : 25 by volume). The X-ray equipment comprised a Rigaku D9C generator, a Rigaku SG-7 Horizontal Diffractometer on which was mounted a Xenon proportional detector, and a standard Rigaku electronic control panel. Analyses were conducted using both chromium $K\alpha$ and molybdenum $K\alpha$ radiation.

The stoichiometry of the sample and the presence of other phases within the sample were checked by the comparison of the integrated intensities of the lines recorded on the X-ray charts [2]. The depth of detectable damage was assessed by observation of the behaviour of the [3 1 1] reflection as etching progressed. From the integral breadths and peak shifts of the lines inferences can be drawn as to the degree of faulting and macroscopic strain which exists below the surface [2].

Surfaces cut from a $GdFe_2$ ingot using range 5 of the spark-erosion machine were too disordered to give rise to diffracted beams. The initial chemical etch of $5\,\mu m$ removed the disordered layer completely. However, besides the reflections due to $GdFe_2$, reflections characteristic of $GdFe_4$ are also observed. On referring to the phase diagram [3] one notices that the hexagonal $GdFe_4$ is formed at higher temperatures than the f c c $GdFe_2$. This is consistent with the fact that the surface has been subjected to temperatures in excess of the boiling point of $GdFe_2$. Since gadolinium has a higher vapour pressure than iron, the molten crater is deficient in gadolinium. On cooling the stoichiometry in some regions probably favours the formation of $GdFe_4$ rather than $GdFe_2$. About 10% of the layer consisted of $GdFe_4$, and this phase was present until $20\,\mu m$ of the material had been etched away. The recovery of the [3 1 1] reflection for $GdFe_2$ is shown in Fig. 1a. A stable diffracted intensity was achieved after $70\,\mu m$ of the surface had been removed. The variation of integral breadth of the [3 1 1] reflection with depth below the surface is also shown in Fig. 1a; the integral breadth being a measure of the mechanical deformation of the specimen [2]. The deformation decreased and reached a stable value at about $70\,\mu m$ below the surface. It is interesting to note that there was no change in the position of the peak as the depth below the surface varied. The position of this peak was displaced to higher 2θ angles than would be expected from calculations using Bragg's law. Such a displacement is consistent with the existence of deformation faults within the specimen, and it would appear that the distribution of these faults has been unaffected by the sparking process. A similar procedure was followed for ranges 3 and 7 of the Servomet spark-erosion machine.
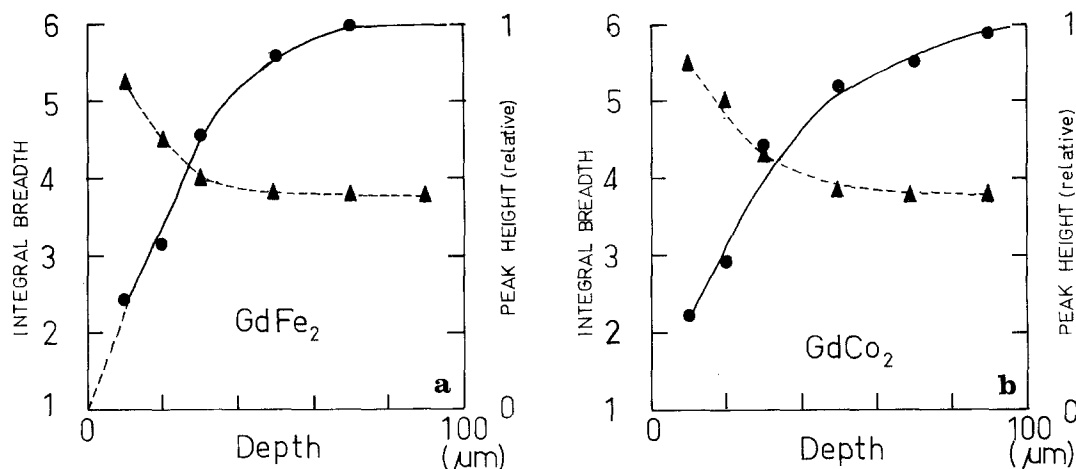
Figure 1 The variation with depth of the peak height and integral breadth of the [3 1 1] reflection from spark-machined surfaces of (a) $GdFe_2$ and (b) $GdCo_2$.

TABLE I Results of experiments performed using the Servomet spark-erosion machine

Material	Servomet Range	Spark Gap voltage (V)	Average Crater Diameter (μm)	Cutting Rate (mm h^{-1})	Depth of Detectable Damage (μm)
$GdFe_2$	3	100	5	5×10^{-2}	200
	5	80	3	1×10^{-2}	70
	7	60	<1	2×10^{-3}	<30
$GdCo_2$	5	80	3	5×10^{-3}	90

The $GdCo_2$ specimens behaved similarly to the $GdFe_2$ specimens. The initial etch showed that some latent (f c c) cobalt was formed. Approximately 5% of this surface layer was cobalt. After some $20\,\mu$m of material had been removed no cobalt reflections were observed. The [3 1 1] reflection grew with successive etching and a stable diffracted intensity was observed after $90\,\mu$m of material was removed. The integral breadth decreased with etching and became constant after $90\,\mu$m of material was removed. There was also a displacement of the peak to higher 2θ values. This displacement remained constant as etching proceeded, which supports the contention that the distribution of deformation faults within the $GdCo_2$ is unaffected by the process of spark-erosion.

The results of the various experiments are collated in Table I. Both the rate of erosion of the samples and the depth of the damaged layer decrease as the energy liberated in each spark decreases. Although the rate of removal of material by the process of spark-erosion is slow for both gadolinium compounds this is well compensated for by the ability one has to manufacture specimens having a wide variety of shapes.

Acknowledgement

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