ANODISING AS A METHOD OF CRACK DETECTION FOR ALUMINIUM ALLOY FORGINGS

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Anodising is a process of electrolytic building up of an insulated oxide film on the surface of metals like aluminium and titanium. Both sulphuric acid and chromic acid anodising are extensively used for the production of protective surface coating against corrosion for aluminium and its alloys. Anodic films are often dyed to give a wide range of attractive colours for decorative purpose. Further, anodic surfaces provide an excellent base for organic paint coatings and plastic adhesive coatings. In addition to the above advantages, chromic acid anodising can be successfully used as an aid to the inspection of aluminium alloy components particularly forgings, stampings and other wrought products for detection of cracks, folds and other surface discontinuities.

Detection of crack by chromic acid anodising is made possible because the process gives an uniform grey appearance throughout the part and any crack or discontinuity appear as a distinct darker line defining the flaw. Also, the chromic acid which enters the discontinuity during the anodising process seeps out and stains the area with yellow or brown colourations. Since, anodising reveals the surface grains, any inclusions or intercrystalline corrosion shows up in the grain patterning. However, a detailed procedure for the detection of cracks by anodising has not been published for routine process control. The effectiveness of the method as compared to crack detection by dye penetrant method is also not known. A systematic study was carried out to arrive at optimum parameters for anodising as a means for crack detection in aluminium alloy forgings and also to assess its effectiveness in relation to dye penetrant method.

EXPERIMENTAL

A number of experiments were carried out to arrive at the optimum process parameters for the detection of cracks by anodising. Specimens were prepared from aluminium alloy forgings. Artificial cracks were produced in specimens by slitting in the middle from one edge using Jeweller's Saw. Slit openings were then closed by cold hammer forge thus simulating a tight crack condition. Faces of specimens containing cracks were reworked by filing and grinding until the crack was not visible to naked eye. Specimen preparation was standardised so that there would be little variation from specimen to specimen. Sequence of specimen preparation as described above are shown by sketch in Figure – 1.



Fig. 1 Stages of specimen preparation

Specimens were vapour degreased in Trichloroethylene bath followed by alkaline degressing in a solution containing 5–15g. washing soda and 5g. tri-sodium-phosphate in a litre of water. Finally, they were washed thoroughly in cold water before anodising treatment.

Anodising was carried out in chromic acid bath containing 30–100g. per litre of chromic acid. Current density was maintained at 0.5–0.7 amps/dm^2 and the bath temperature 40±2°C. Voltage was slowly raised from 0 to 40 volts in steps of 2 to 4 volts in the first 10 minutes. At 40 volts, holding time was varied from 10 to 60 minutes for different specimens. Finally voltage was stepped upto 50 volts in 5 minutes and held for 5 minutes Before the specimens were removed from anodising bath voltage was reduced to 0. Specimens were immediately cleaned in cold water and suspended for drying. Figure–2 shows the process cycle of operation (time vs. voltage) for different specimens.

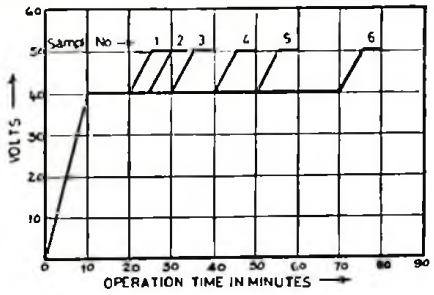


Fig. 2 Process cycle of variation in time with voltage

After a period of 2 hours specimens were examined for detection of cracks and there afterwards periodically for the next 24 hours to see if there is any change in the crack indication, or in the degree of sweepage of chromic acid from the crack. Some variations from the above voltage vs. time cycle, as well as effect of intermittent reversal of polarity for short duration during operation, were studied to see whether these had any advantageous effect. Based on these experimental results optimum conditions for anodising for crack detection were standardised. Additional experiments were conducted, using this data for anodising, as detailed below;

—Experiments on the effectiveness of dye penetrant inspection compared to anodising method for detection of open cracks and reworked cracks. Specimens selected for these experiments were similar in design as shown in Figure—1.

—Experiments on the sensitivity of anodising method in detecting very fine crack compared to dye penetrant method. In this experiment a specimen having multiple cracks branching in different directions was produced on a alclad Al—alloy plate by localised heating and introduction of impact stress. Specimen was subjected to both dye penetrant as well as anodising operations for comparison.

—Experiments on the effectiveness of anodising method for detecting oxide folds and other surface defects in forgings. This was carried out by subjecting the actual production components to both dye penetrant inspection as well as anodising for crack detection.

In all the above experiments specimen surfaces were subjected throughout to visual examination followed by examination under stereomicroscope (35X) and finally cut sections were examined under optical microscope (1000X) wherever considered necessary.

RESULTS AND DISCUSSION

Experimental results on the effect of variation in anodising time, process voltage and reversing of polarity on the crack revealing characteristics of anodising is shown in Table 1. Sample Nos. 1 to 6 give the effect of variation in holding time. It can be seen that the detectability of crack progressively improved as the holding time at 40V was increased from 10 to 20 minutes. No appreciable difference was observed between 20 minutes and 30 minutes holding time. However, when the holding time was further increased from 40 to 60 minutes cracks become less distinct.

This observation is explained from the following considerations. The chromic acid for anodising has a solvent action on the aluminium oxide film thus making it a porous cell. During the initial stages of anodising the thin flown metal over the crack breaks down due to the oxide formation and dissolution. Once the crack is open, anodising continues at the edge of the crack making it visible. As the process continues, the film thickness increases with time and gives a good revealing characteristic after 20–30 minutes of holding time. Further increase in film thickness with time seems to have blocked the crack with the film, thus decreasing its effectiveness.

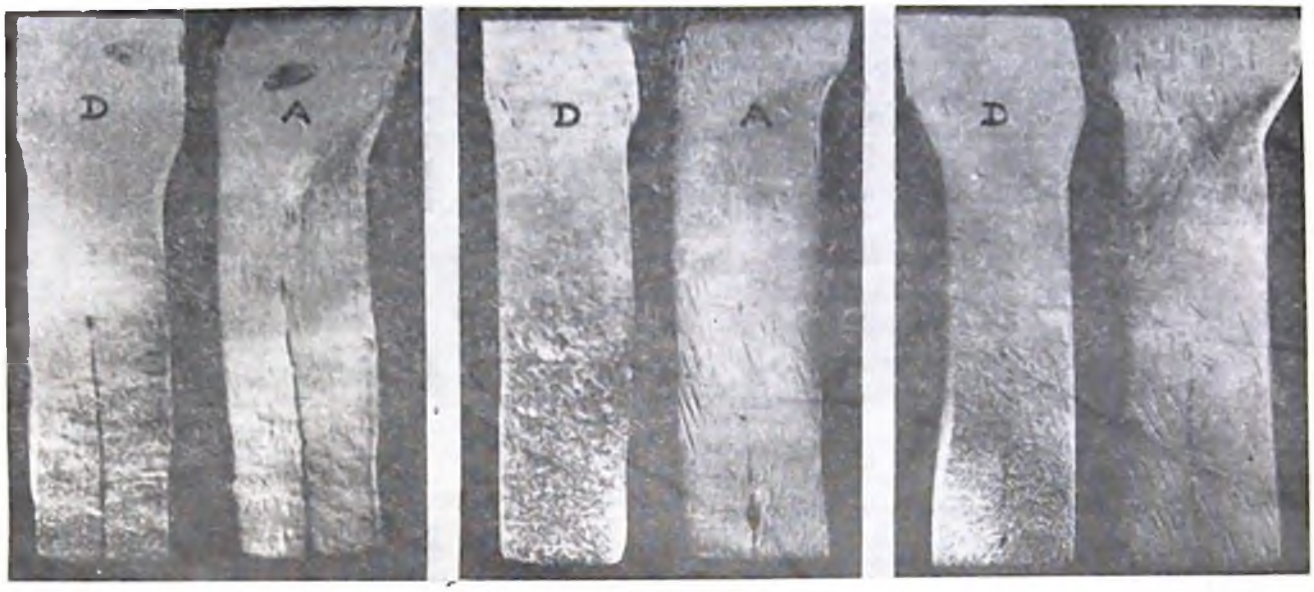
Experiments conducted by holding only at 40 volts for different times eliminating raising to 50 volts (sample 7–9) as well as raising the voltage directly to 50 volts and eliminating holding period at 40 volts (sample 10) showed poor crack revealing characteristics. From this it can be surmised that holding both at 40 volts and 50 volts serves separate functions in revealing the cracks. Possibly holding at 40 volts functions in opening out the crack and holding at 50 volts gives a more coherent film thus making it well defined. Additional experiments involving reversal of polarity during operation (sample 11—14) although showed some improvement on the crack revealing property, the effect was not appreciable enough for further experimentation.

Inspection of specimens after 2 hours of anodising treatment and further periodic examination for the next 24 hours did not change the revealing characteristics of the crack or the degree of seepage.

Based on the above data it was considered that with solution concentration, current density, operating temperature and other process details remaining the same as described in the text, the best condition for crack detection was for a voltage-time cycle of 20 minutes at 40 volts and a further 5 minutes at 50 volts

In practice, parts showing surface defects are reworked within dimensional tolerance by grinding, scooping etc and are subjected to resurface inspection.

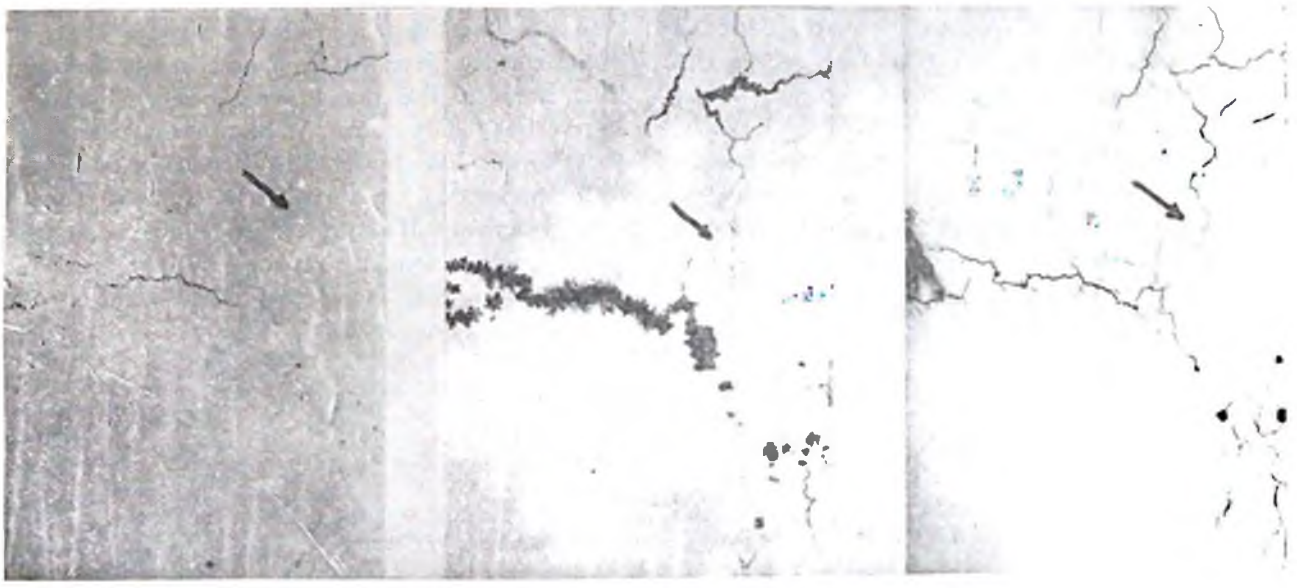
In reworked components there is a tendency of the defect to be camouflaged by metal flow. Results of experiments carried out to compare the effectiveness of anodising process and dye penetrant inspection for reworked components, are indicated in Figure-3.



(a) (b) (c)

Fig. 3

Shows comparative indications observed after Dye Penetrant Inspection (D) and Anodising Treatment (A) (a) specimen with crack open to surface; (b) specimen with reworked crack where crack is camouflaged by flown metal; (c) specimen same as (b) and then etched for 5 minutes in 6% NaOH solution before treatment



(a (b (c)

Fig 4

Shows comparative assessment of anodising and dye penetrant methods (a) cracks as seen on surface with naked eye; (b) indications observed on the same sample after dye inspection; (c) indications observed after anodising.

Comparing Figure-3 (a), it is clearly seen that anodising and dye penetrant are equally effective in the detection of tightly closed cracks open to surface. But anodising is far more effective when such cracks are camouflaged by reworking [Fig.3 (b)] even when such reworked cracks specially prepared by etching [Fig.3 (c)]. This advantage for anodising is due to the solvent action of chromic acid on aluminium oxide as discussed earlier. This would mean that anodising method can be, and should be introduced as a complimentary method to dye penetrant inspection in case of reworked forgings. In such case, dye penetrant inspection should be performed prior to anodising operation as otherwise there would be dye pick up in the anodic film. Anodising will also have an added advantage of protecting the surface.

Results of experiments conducted to compare the sensitivity of anodising method and dye penetrant method in revealing cracks are shown in Figure-4.

It is found that that the anodising method indicates the cracks with a very high degree of definition as can be seen by comparing region 'A' marked in Figure-4 (a), (b), (c). In this region, fine cracks which are not visible by the naked eye and which are very slightly indicated by dye penetrant method are clearly indicated by anodising method.

In the evaluation of anodizing method for detection of oxide folds and other defects in forgings, it was found that anodising revealed the surface grains and thus made it possible to detect oxide fold in forgings. Figure-5 shows a forged component after anodising showing clear indications of grain pattern and fine demarcation marks of a fold in this forging. The part prior to anodising was subjected to dye penetrant inspection which did not show any indications.



Fig. 5 A forging fold revealed by anodising. Note the grain patterning close to the fold.

CONCLUSIONS

Anodising can be used as a non-destructive testing method for detection of surface defects such as cracks and folds on aluminium alloy forged components. Best results are achieved by anodising in chromic acid bath for holding time of 20 minutes at 40 volts followed by stabilizing for 5 minutes at 5 volts. Reversal of polarity during the process, although indicated some improvement, this is not very significant. Anodising method is more sensitive in the detection of fine cracks as revealed from these experiments and it is more effective than the dye penetrant method in revealing tightly closed and reworked cracks where the reworking has a tendency to camouflaged the cracks by flown metal on the surface. In addition, the anodising method will also reveal oxide folds in forgings which are not normally revealed by dye penetrant method when they are not associated with any discontinuity open to surface.

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TABLE—1

EFFECT OF VARIATION IN (A) ANODISING TIME, (B) PROCESS VOLTAGE AND (C) REVERSING OF POLARITY ON REVEALING REWORKED TIGHT CRACKS

Sample No.	PROCESS CYCLE			OBSERVATION		
	Holding time at 40 volts in mts.	Holding time at 50 volts in mts.	Intermittent reversal of polarity	Revealing characteristics of crack (visual) and Degree of seepage of chromic acid	Examination by Stereo microscope X35	Detectability grading
1	10	5	—	Not clearly visible with slight seepage	Very fine crack open to surface	Poor
2	15	5	—	Clearly visible with intermittent seepage	Fine crack open to surface	Fair
3	20	5	—	Clear and good visibility with negligible seepage	Slight broadening of crack open to Surface	Good
4	30	5	—	Clear and good visibility with negligible seepage	Slight broadening of crack open to surface	Good
5	40	5	—	Clearly visible with negligible seepage	Fine crack open to surface	Fair
6	60	5	—	Not clearly visible with no seepage	Very fine crack open to surface	Poor
7	5	—	—	Not visible with no seepage	Crack not open to surface	Poor
8	10	—	—	Poor visibility with no seepage	Crack barely open to surface	Poor
9	15	—	—	Not clearly visible with considerable seepage	Fine crack open to surface	Poor
10	—	10	—	Not visible with no seepage	Not open to surface	Poor
11	30	5	One reversal for 1 min. after 15 min. at 50volt	Clearly visible with considerable seepage	Slight broadening of crack open to surface	Good
12	30	5	Two reversals for 1 min. each after 10 & 20 mins. at 40volt	Clear and good visibility with some seepage	Slight broadening of crack open to surface	Good
13	10	—	One reversal for 1 min. after 5 mins. at 40volt.	Not clearly visible with some seepage	Very fine crack barely open to surface	Poor
14	30	—	Two reversals for 1 min. each after 10 & 20 mins. at 40volt	Clear and good visibility with considerable seepage	Slight broadening of crack open to surface	Good

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