

PAPER REF: 2960

MAKING THE CUT FOR THE CONTOUR METHOD

P John Bouchard^{1(*)}, Peter Ledgard¹, Stan Hiller¹, Foroogh Hosseinzadeh¹

¹Materials Engineering, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom

(*)Email: p.j.bouchard@open.ac.uk

ABSTRACT

The contour method is becoming an increasingly popular measurement technique for mapping residual stress in engineering components. The accuracy of the technique is critically dependent on the quality of the cut performed. This paper presents results from blind cutting trials on austenitic stainless steel using electro-discharge machines made by three manufacturers. The suitability of the machines is assessed based on the surface finish achieved, risk of wire breakages and the nature of cutting artefacts introduced.

Keywords: residual stress, wire EDM, surface quality

INTRODUCTION

The contour method is a relatively new destructive technique for measuring residual stress in engineering components. It is based on the assumption that when a planar cut is made in an engineering component, the cut surface will relax and undergo displacements which, in turn, can be measured and used to determine the magnitude and distribution of the original residual stresses present. Advantages of the contour method are that it provides a two-dimensional map of residual stress on the cut surface, it can be implemented in the laboratory with widely available cutting and measurement equipment and it is not limited by microstructure or the thickness of the component [1].

The success and accuracy of a contour measurement is critically dependent on the “quality” of the cut. Wire electro-discharge machining (EDM) is the cutting process of choice for the contour method, as it does not work harden or deform the material excessively during cutting, but little is known about the influence of wire EDM machines and their cutting parameters on the quality of surfaces produced for contour measurement.

The purpose of the present study was to evaluate the suitability of three wire electro-discharge machines made by different manufacturers denoted A, B and C, for making high quality cuts for contour residual stress measurements. This was achieved by asking the manufacturers to undertake blind cutting trials on two types of welded test component. We first characterise several undesirable surface features that can sometimes arise from wire EDM cuts for contour measurements. Secondly we describe the test components, the purpose of the trials and the instructions given to the vendors. Selected results of the trials are then presented and conclusions drawn regarding the most suitable machine.

WIRE EDM CUT SURFACE ARTEFACTS

The wire EDM cutting process is illustrated in Fig. 1. It is a non-contact technique that uses an electrically charged thin moving wire where the energy contained in a spark is used to remove material. The contour method requires a single high quality cut to be made dividing

the body of interest into two halves. This differs from normal wire EDM practice where a roughing cut is followed by several “finishing” or “skim” cuts in order to achieve close precision surfaces of low roughness. Ideally, the cut faces of the body after a single contour cut should be perfectly flat when no residual stress is present. Thus a primary requirement for a good quality contour cut is to produce nominally flat cut faces with low surface roughness.

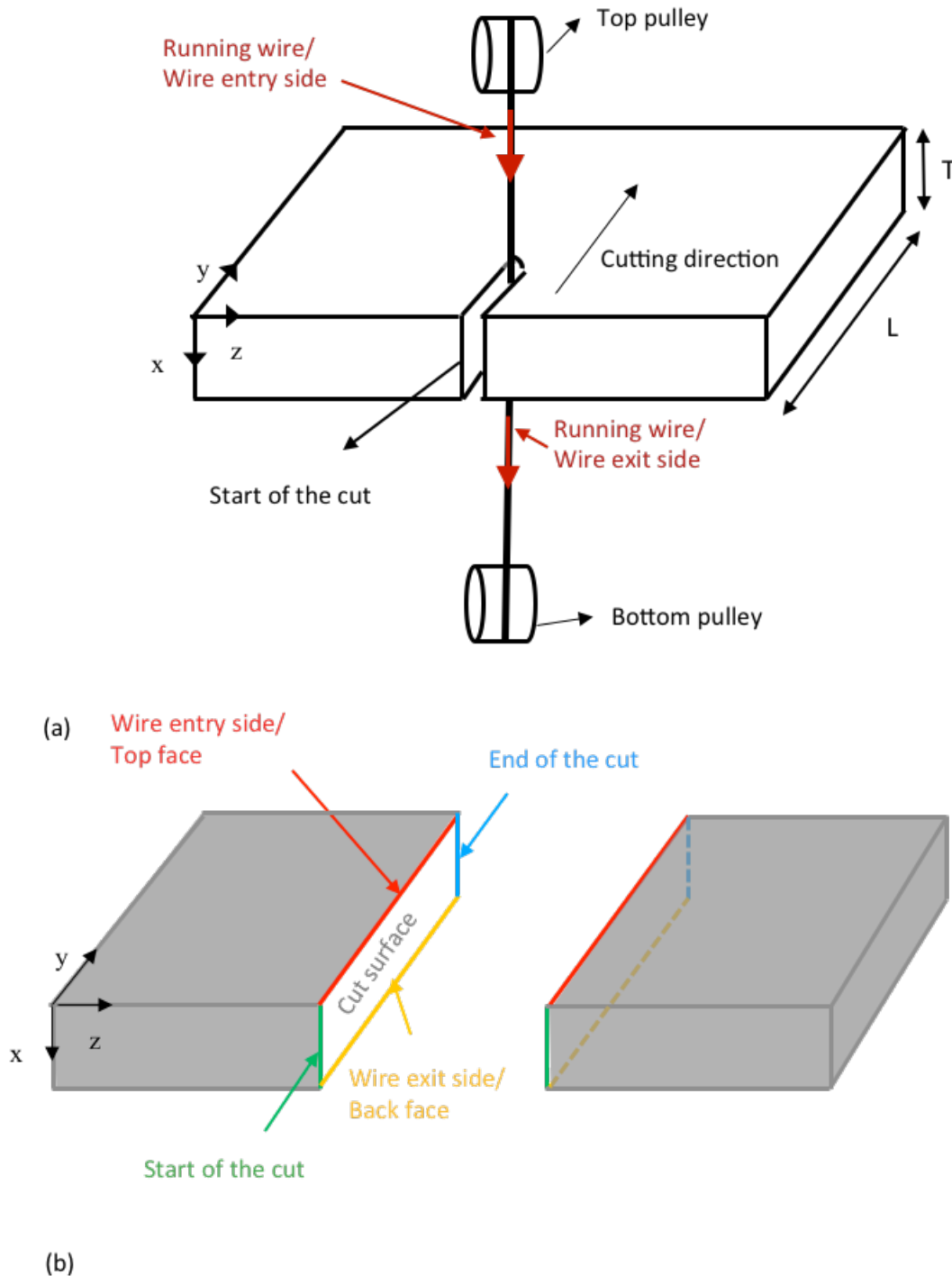


Fig.1. (a) Schematic drawing of component being cut by wire EDM, (b) labeled edges of cut parts

However, the wire EDM process often introduces topographic features on the cut surfaces. For example, discontinuities from wire breakage and cutting instability (ledges), transient effects at start of cutting, surface waviness, surface bowing and wire entry/exit artefacts. Some of these “cutting artefacts” are illustrated in Fig. 2. Such artefacts can be classified as having either symmetric or asymmetric characteristics. The former are of most concern for contour residual stress measurement because they are not cancelled out during the data analysis procedure. Likewise topographic artefacts having a length-scale, across the cut plane, greater than the wire diameter are not removed by the data smoothing process. Thus for reliable and accurate contour residual stress measurements, it is important to avoid (or control) introduction of both discontinuity features and symmetric topographic artefacts having a long length-scale in the wire EDM cutting process.

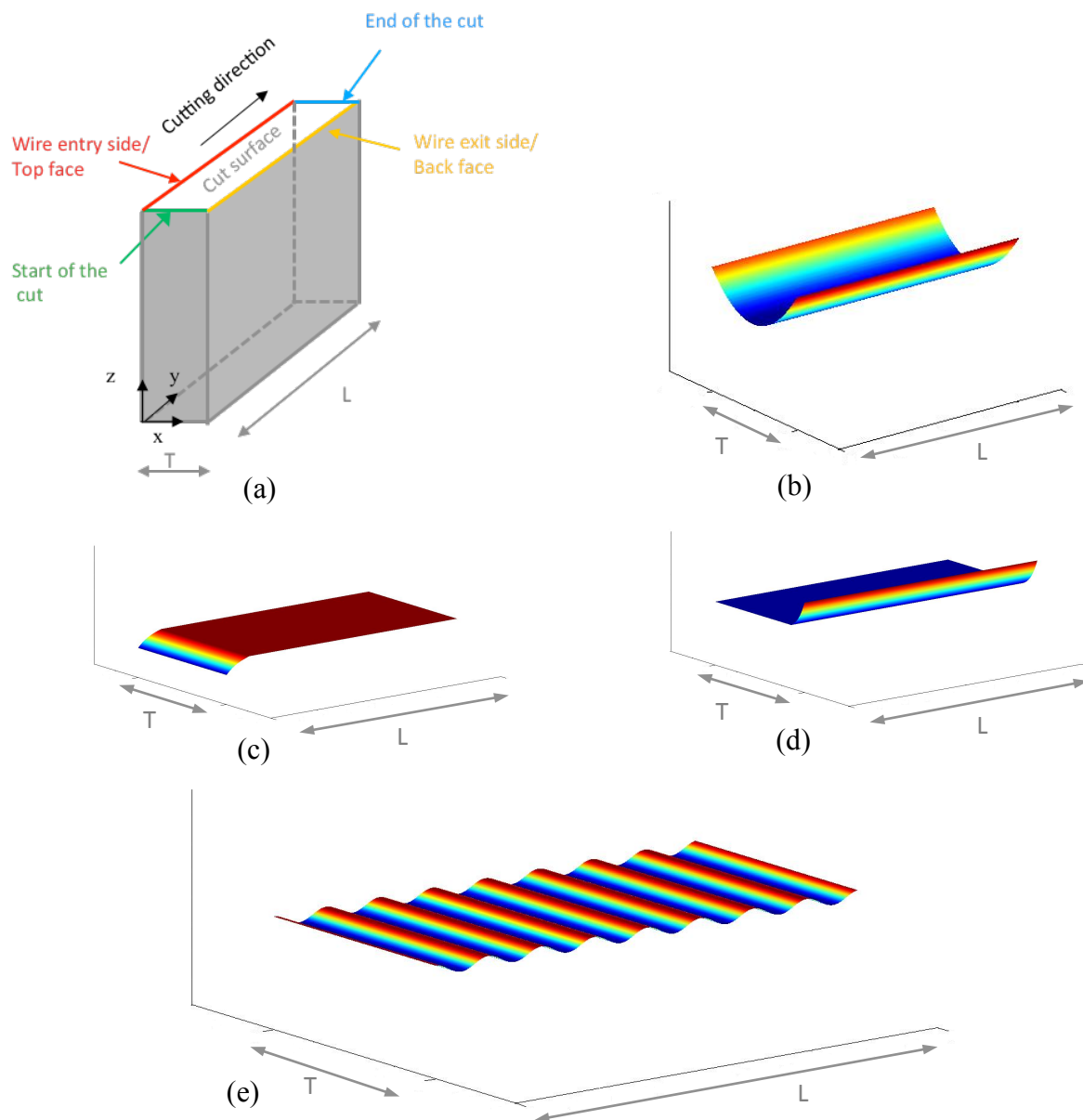


Fig.2. Diagrams illustrating of types of wire EDM cutting artefacts: (a) cut face, (b) surface bowing, (c) cut start transient, (d) wire exit artefact, and (e) surface waviness

Wire EDM is controlled by a large number of cutting parameters. Manufacturers have developed sophisticated control systems, with simplified operator interfaces, that optimise conventional EDM processes (i.e. rough cut followed by skim cuts) for material, thickness, surface finish, speed of cutting etc. But these systems are not designed for single pass high quality contour cuts. Optimisation of cutting parameters for contour cuts is well beyond the scope of the present paper. Instead the performance of different types of wire EDM machines is assessed from “blind” contour cutting trials undertaken by three different manufacturers as part of a competitive procurement process. The results from the trials are compared in terms of surface finish (R_a value) achieved and the nature of cutting artefacts introduced.

TEST COMPONENTS

Two test components containing residual stress were chosen for the blind cutting trials on each machine. A 60 mm thick, 240 mm wide austenitic stainless steel plate containing an electron beam (EB) weld at mid-width (Fig. 3a) was chosen to test the capability of machines in dealing with a long wire contact length (≈ 240 mm) and the presence of weld defects (blow holes). The second component (Fig. 3b), also made from stainless steel, had a complex outline geometry and contained two manual metal arc welds; this component was chosen to see how well the wire EDM machines coped with rapid changes in cross section (i.e. wire contact length).

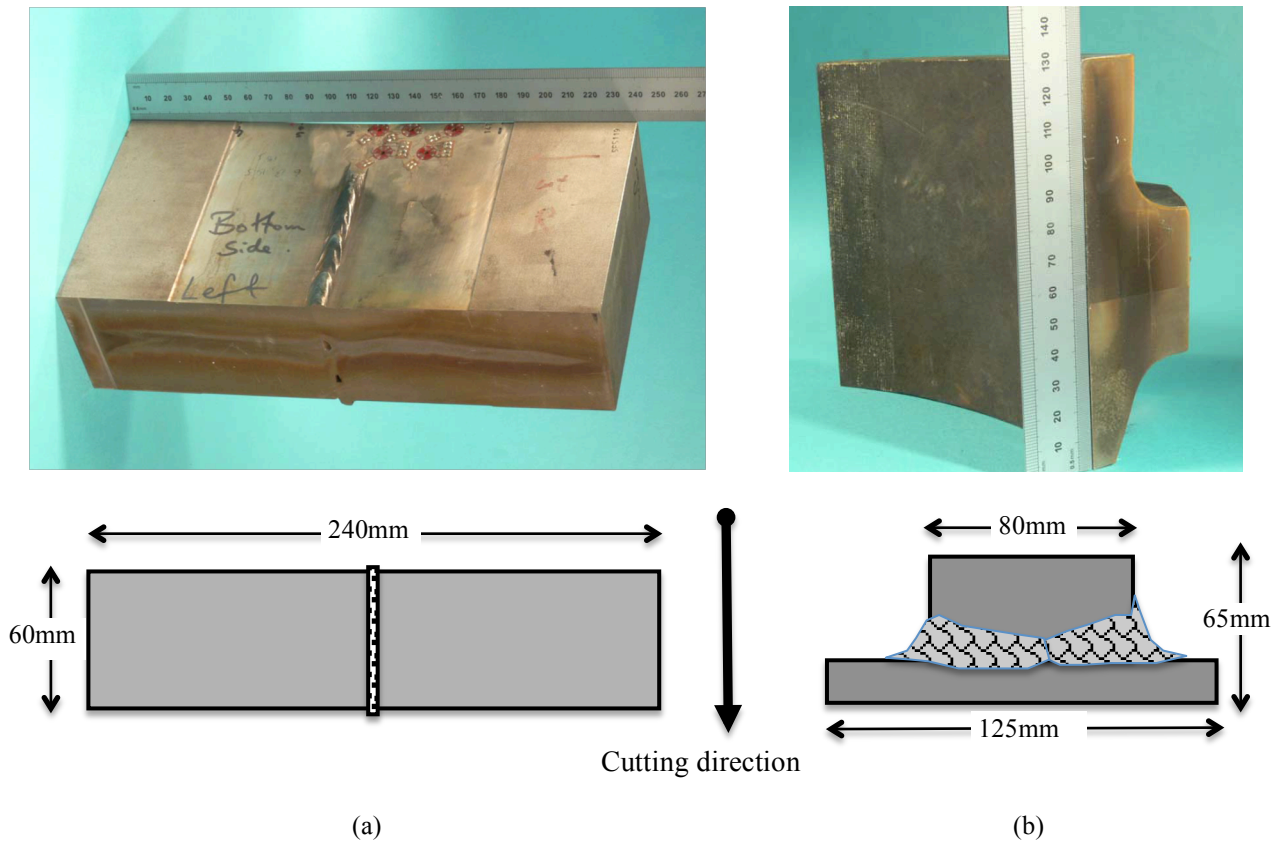


Fig.3. Specimens for cutting trials, (a) electron beam welded plate, (b) complex geometry weld

SPECIFICATION FOR BLIND CUTTING TRIALS

Each EDM machine type (A, B and C) vendor was supplied with the two types of welded test component and instructed to:

- clamp one side only (specific jigs or fixtures not required)
- use 0.25mm diameter wire
- use the cutting direction as depicted in Fig. 3
- undertake the cut with a single pass
- aim to produce a constant, minimum width cut
- offer one additional cut (optional)

The vendors were advised that the trials would be witnessed and the resulting cuts assessed for quality of cut surface "contour", surface finish, best edges and least surface damage (depth of recast layer).

RESULTS OF TRIALS

The surfaces of the unclamped halves of all the test samples were examined by eye and touch. Discontinuities in the surface profiles from wire breaks were evident on some of the surfaces, for example see Fig. 4. These occurred at the edge of weld defects in the EB welded plate component or at rapid changes in geometry in the complex component. Ledges in the surface profiles made by manufacturer A occurred on both types of component, see Figs. 4 - 6.

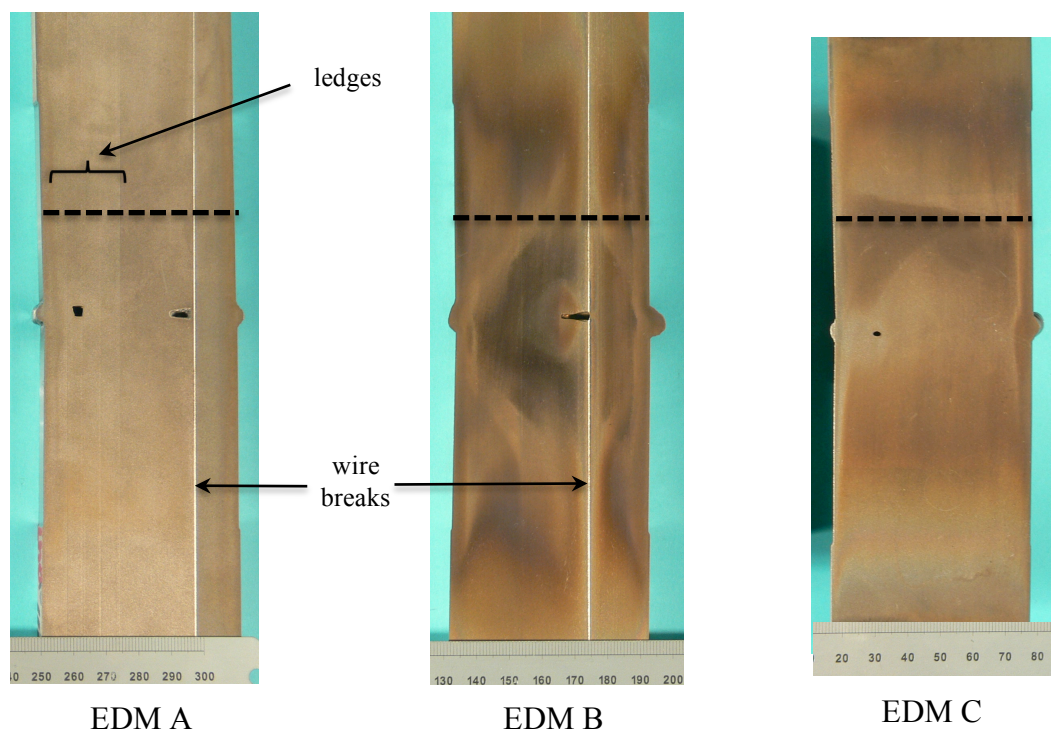


Fig.4. Cut surfaces of the 240 mm long x 60 mm deep EB welded test components showing the weld blow holes and evidence of wire breakages and ledges. The chained line indicates the approximate location of the surface line scans shown in Fig. 5.

The mean surface roughness of each test surface was measured using a standard Talysurf. A matrix of 32 scans were undertaken parallel to and perpendicular to the wire cutting direction and distributed over the surface of each specimen. The results of this survey are summarised in Table 1 from which it is seen that all three machines produced similar surface roughness levels. Given the similarity between the surface roughness levels achieved by each machine no further work was done to compare the depth of the recast layer.

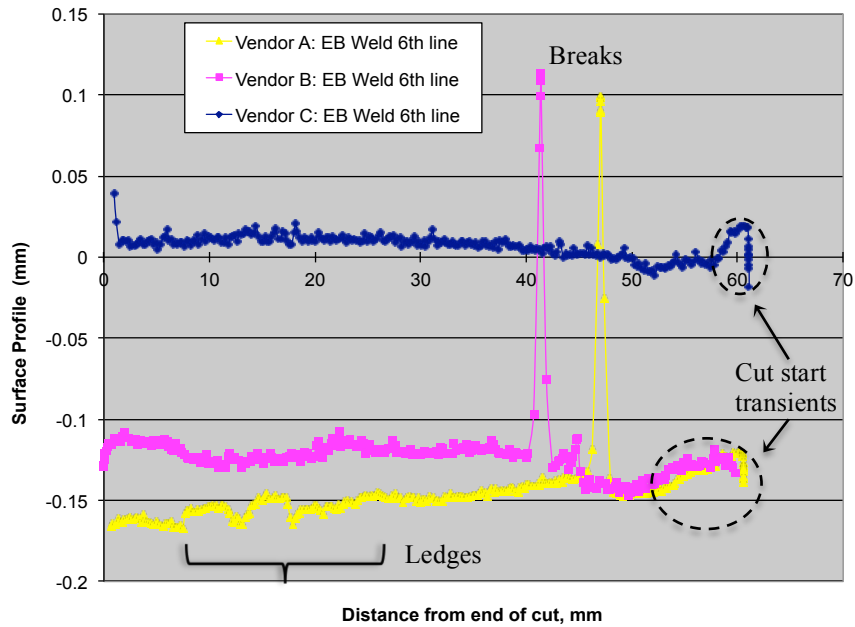


Fig.5. Comparison of through-thickness surface topography profiles from near mid-length of the EB welded components

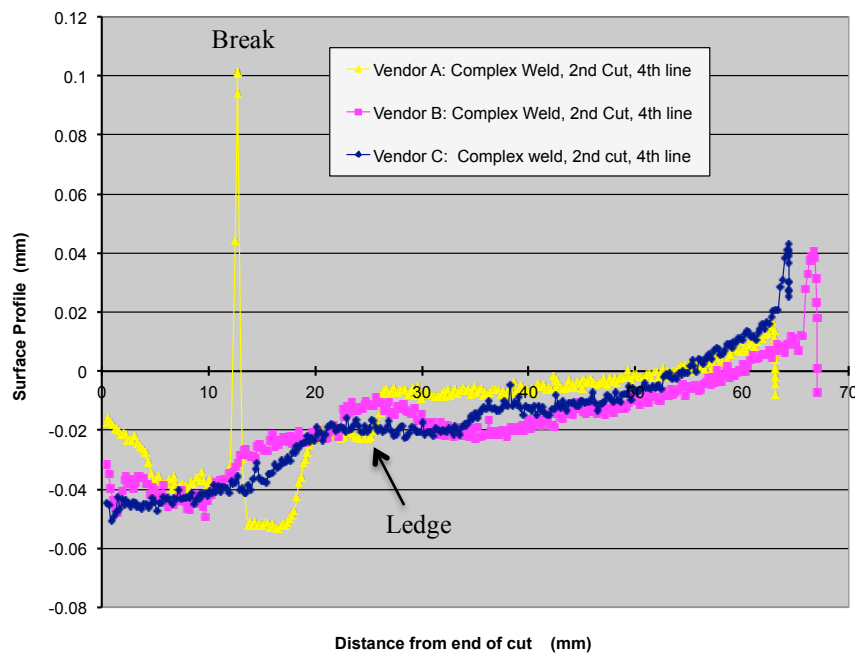


Fig.6. Comparison of through-thickness surface topography profiles from near mid-length of the complex geometry welded components

The surface topography of each unclamped surface was measured using a Mitutoyo Coordinate Measuring Machine with 3 mm diameter ruby tipped drag probe. Surface profiles were measured parallel to and perpendicular to the cutting direction at common locations and compared with each other, for example see Figs. 5 and 6. The EB weld surface profiles shown in Fig. 5 illustrate wire breakages (EDM types A and B) and the presence of start of cutting transient effects. It is evident that EDM type C had the shortest start transient length-scale and this was also the case for other surface line scans in this geometry. The complex geometry weld surface profiles in Fig. 6 show another wire break and the presence of a ledge in the profile of EDM Type A. The quality of the edges of the cut surfaces (flatness and squareness at the edge) was examined by extracting small specimens from the wire entry and exit sides of the EB weld components and optically examining prepared cross-sections but it was not possible to discriminate any differences.

The overall performance of the EDMs for carrying out contour cuts was assessed based on the inspection outcomes summarised in Table 1. It was concluded that the machines achieved similar surface roughness levels but that wire EDM C out-performed the two other machines in terms of avoiding wire breakage and minimising cutting artefacts, and was therefore the best suitable machine to use for contour method residual stress measurements.

Table 1 Outcomes of “blind” wire EDM cutting trials

Specimen	EDM Type A	EDM Type B	EDM Type C
240mm EB Weld	<ul style="list-style-type: none"> ➤ Wire break ➤ Start of cut transient distance = 5 -10 mm. ➤ Ledges evident. ➤ Ra = 2.90 	<ul style="list-style-type: none"> ➤ Wire break ➤ Start of cut transient distance = 5 -10 mm. ➤ Ra = 3.01 	<ul style="list-style-type: none"> ➤ No wire break ➤ Start of cut transient cut distance < 5 mm ➤ Ra = 3.25
Complex weld, Cut 1	<ul style="list-style-type: none"> ➤ Ledges in profiles at changes in geometry ➤ Ra = 3.39 	<ul style="list-style-type: none"> ➤ Wire break ➤ Ra = 2.92 	<ul style="list-style-type: none"> ➤ Well behaved surface displacement profiles ➤ Ra = 2.33
Complex weld, Cut 2	<ul style="list-style-type: none"> ➤ Wire break ➤ Ledges in profiles at changes in geometry 	<ul style="list-style-type: none"> ➤ Minor ledges in profile at change in geometry ➤ Ra = 2.98 	<ul style="list-style-type: none"> ➤ Well behaved surface displacement profiles ➤ Ra = 2.51

CONCLUSION

Results from blind cutting trials on welded stainless steel test components have been used to assess the suitability of different types of wire EDMs for contour residual stress measurements. It was shown that EDM type C out-performed two other machines in terms of risk of wire breakages and the nature of cutting artefacts introduced.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the close cooperation of EDM manufacturers in undertaking blind cutting trials and the work of PhD student Burak Toparli who assisted in measuring the test samples. The research is co-funded by the East Midlands Development Agency and Rolls-Royce.

REFERENCES

1. Prime, M B, Cross-sectional mapping of residual stresses by measuring the surface contour after a cut, *J of Eng. Mats & Techn.*, 2001, 123(2): p. 162-168.