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A New Technology for Field Testing of the Plasticity of Rails

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Abstract

This paper relates to the application of a novel technology to measurement of the mechanical properties of sections of rail steel, and of welds between them. The outcome of this type of test – ie the stress-strain relationship of the material – is much more informative than the numbers obtained by hardness testing, which should be regarded as no better than semi-quantitative indicators of the resistance of the metal to plastic deformation. Stress-strain curves, on the other hand, can be used in fully quantitative modelling of how the rail will respond to further periods in service – particularly since the testing can be carried out at a series of depths. Although this type of testing is thus much more informative than hardness testing, it can be carried out in a similarly quick and convenient way. Results presented here, and also large amounts of other work published over the past few years, have confirmed a high level of consistency between PIP-derived curves and those obtained via conventional uniaxial testing. It has also been shown that variations in the properties across the width of a flash butt weld can be picked up with a spatial resolution of the order of a millimetre. An ongoing project is aimed at the development of a portable version of the PIP facility, which will be suitable for application to rails.

Keywords: indentation, mechanical properties, steel, weld, plastometer, rail.

1 Introduction

This paper concerns a novel methodology for obtaining stress-strain curves from spherical indentation measurements, which is quick and simple to carry out, and suitable for field testing. It combines the convenience of hardness testing with the rigorous outcomes of tensile testing. It is termed profilometry-based indentation plastometry (PIP). It involves finite element method (FEM) modelling of the indentation, with plasticity parameters being repeatedly changed to give optimal agreement between experimental and predicted indent profiles. It is the outcome of an extended period of research and development, much of which took place in Cambridge University. A benchtop facility is now commercially available – see www.plastometrex.com. Indentation, profile measurement and iterative FEM modelling are all fully automated, giving stress-strain curves within a few minutes. An ongoing project concerns portable versions, suitable for field testing of components such as pipelines and rails. Application to sections of rail, using the benchtop machine, is described here. A photo of this facility is shown in Figure 1.

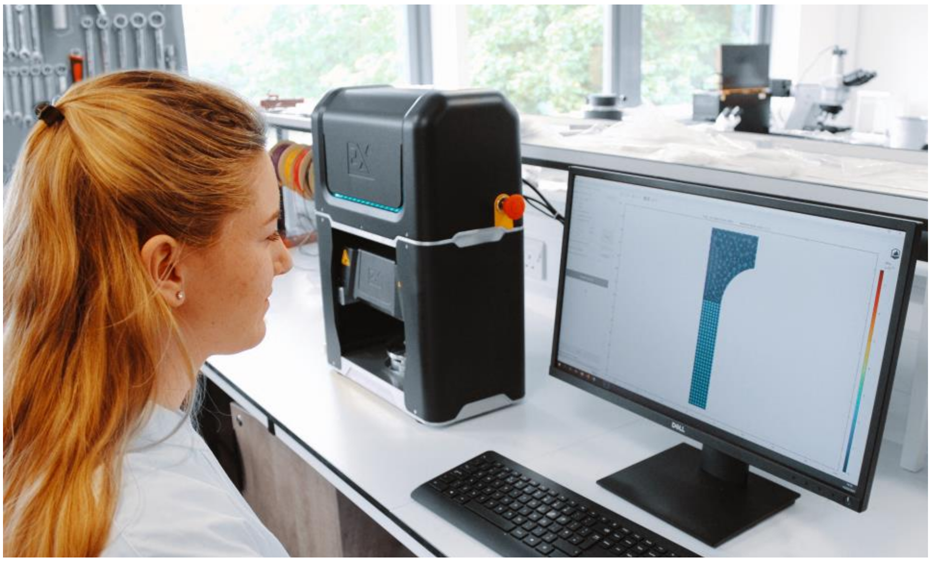

Figure 1: The PLX bench plastometer in use.

Advantages, compared with tensile testing, include minimal preparation requirements and a capability to map over a surface, and with depth, on a relatively fine scale. These are also offered by hardness testing, but hardness numbers are no better than semi-quantitative guides to metal plasticity [1]. A recent review of PIP [2] covers optimisation of experimental and data handling procedures. Other recent papers concern anisotropy [3], residual stresses [4], application to very hard metals [5] and property variations around fusion welds [6].

An area of potential use relates to components in which certain regions – often at free surfaces – have become hardened. This may be done deliberately, to improve resistance to wear or crack initiation, while leaving the interior relatively soft – ensuring good toughness retention. It can also happen inadvertently during service – for example, due to passage of wheels over rails [7]. Having stress-strain relationships for material at different depths in such hardened layers is potentially of considerable value – for example in predicting how the component will respond to further loading, assessing the potential for crack formation [8] etc. Uniaxial testing is clearly unsuitable for this. It is sometimes claimed that “nanoindenters” can be used to obtain stress-strain relationships with fine scale resolution. However, a key finding over recent years [2] is that the plastically-deformed volume must be large enough for its mechanical response to be representative of the bulk. This usually requires it to be "many-grained", typically translating into a need for an indenter radius of around 0.5 to 1mm and a load capability in the kilonewton range. "Nanoindenters" (typically with load capabilities below about 10N) are completely unsuitable and do not give reliable results.

2 Methods

The sample tested was a crown section of rail incorporating a (flash butt) welded joint. The rail material was a standard (R260) pearlitic steel [9, 10]. No details are available concerning conditions used either for rail production or for the welding operation. The sample had not been used in service. Tensile samples, oriented so that the loading was along the length of the rail, were parallel-sided, with a thickness of 4mm. The reduced section part had a width of 6mm and a length of 30mm, with the clip gauge being 25mm long. The loading frame was an Instron 3369, with a 50kN capacity.

PIP testing was carried out on the top of the crown, at a series of points along the length. The surface was first subjected to a standard grinding operation. The points covered the whole of the weld and extended to the parent sections on both sides. Four steps are involved in obtaining a tensile nominal stress-strain curve from a PIP test. These are: (a) pushing a hard spherical indenter (of Si_3N_4, with a radius of 1mm) into the sample with a known force; (b) measuring the (radially-symmetric) profile of the indent; (c) iterative FEM simulation of the test until the best fit set of (Voce) plasticity parameter values is obtained; and (d) converting this true stress – true strain relationship to a nominal stress – nominal strain curve (for tensile loading). The indent topographies were measured using the integrated stylus profilometer, which has a resolution of about 1µm. The indents typically had a depth of about 150µm. All indent profiles were measured in multiple directions, to check for the presence of anisotropy – which is apparent as a lack of radial symmetry. In the present study, all indents were radially symmetric.

3 Results

Figure 2 shows a comparison between nominal stress – nominal strain curves, as obtained by tensile testing and by PIP testing. The agreement is good, with the yield stress being around 500-550MPa and the ultimate tensile strength (UTS) about 900-950MPa. This steel has a relatively high initial work hardening rate, which is common for pearlitic steels. Data from PIP testing across the weld are presented in Figure 3. These data are in the form of plots of yield stress and UTS, as a function of distance from the centre of the weld. There is no scope for comparison between these values and corresponding ones obtained by conventional testing, since the latter cannot be carried out on this scale. Nevertheless, the data for points remote from the weld are consistent with the values in Figure 2.

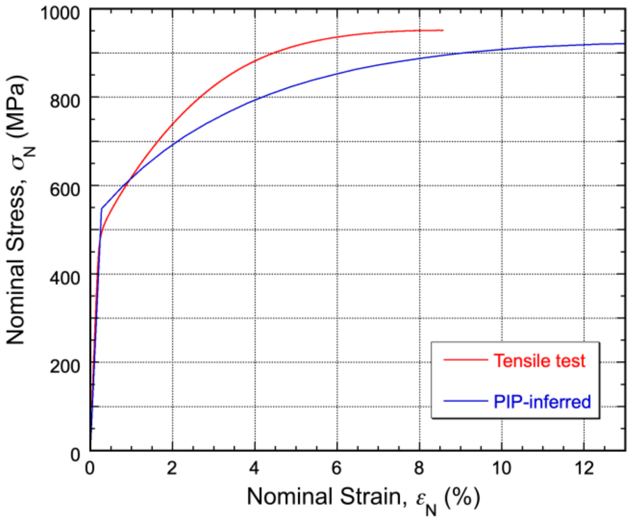

Figure 2: Nominal stress-strain curves for the steel, obtained by tensile testing and by PIP testing.

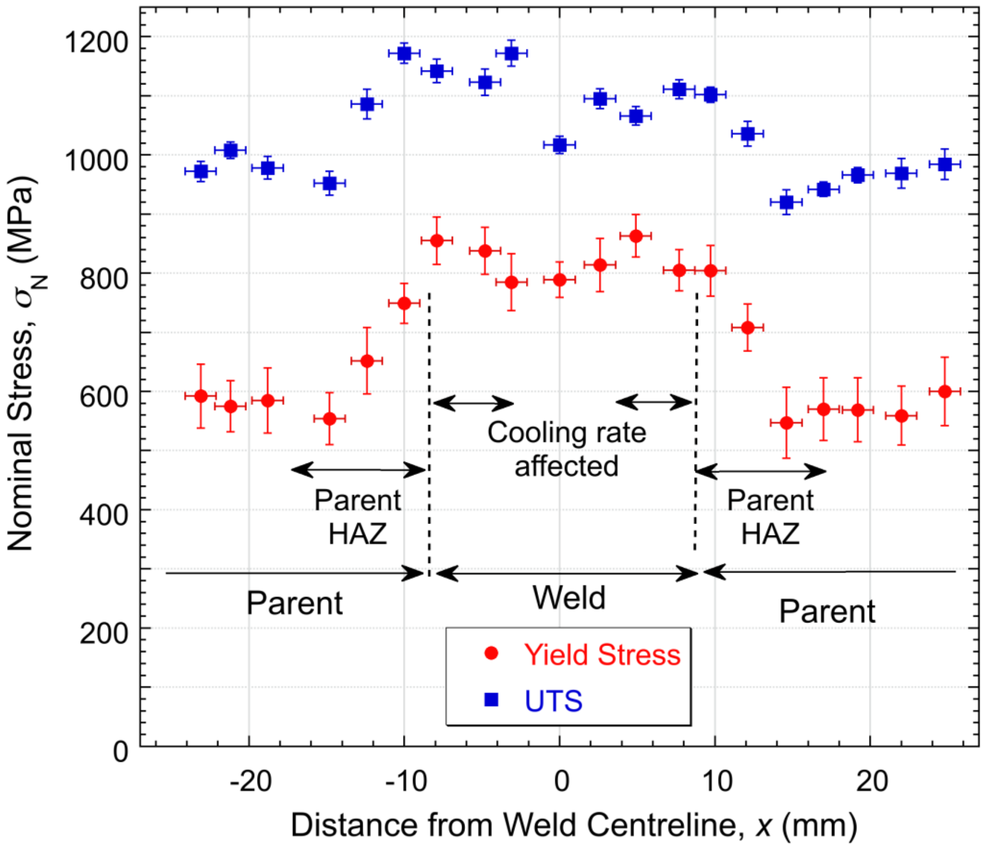

Figure 3: PIP-derived yield stress and UTS data, plotted against distance from the weld centre-line, for a sample containing a flash butt weld.

4 Conclusions

This paper has described the application of a novel technology to measurement of mechanical properties of sections of rail steel, and of welds between them. The stress-strain curves produced by PIP are much more informative than the results of hardness testing, and can be used for quantitative modelling of how components such as rails will behave in service. The results presented here confirm that the stress-strain curve from PIP testing, with rapid sample preparation and testing, aligns well with the results of a conventional uniaxial tensile test. Variations in yield stress and UTS were successfully mapped across a flash butt weld with a resolution of the order of a millimetre.

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