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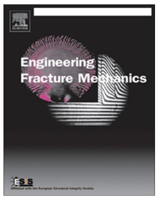

On the use of linear-elastic local stresses to design load-carrying fillet-welded steel joints against static loading

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ABSTRACT

This paper uses local linear-elastic stresses to estimate the static strength of steel arc welded joints. The proposed design methodology was developed by taking as a starting point the fundamental concepts on which the Theory of Critical Distances (TCD) is based. The overall accuracy of the devised approach was checked against a number of experimental results taken from the literature and generated by testing a variety of welded geometries. Such a systematic validation exercise demonstrated that the TCD is highly accurate in estimating the static strength of arc welded joints irrespective of the complexity of the assessed welded detail's geometry.

1. Introduction

Reviews both in the USA and Europe [1,2] indicate that in-service breakage of engineering structures and components costs around 4% of GNP in industrialised nations, the price which has to be paid becoming socially unacceptable whenever failures result in loss of human lives. In this complex scenario, one of the most difficult challenges faced by the metalworking sector is improving the in-service performance of structural assemblies by limiting not only the weight, but also the associated production, maintenance and energy costs.

With regard to the technological issues involved in the manufacturing process, it is well-known that a challenging aspect of making high-performance structures and components is efficiently joining together the different parts. In this context, welding definitely represents the most widely used technological solution. In addition, welding plays a primary role in the repair and life extension of components and structures.

Although several welding technologies are used in manufacturing, arc welding is the most commonly adopted joining technology. As far as conventional arc welding is concerned, producing high quality weldments requires experienced welders capable of properly setting the necessary technological parameters. The overall quality of a weld mainly depends on the material microstructural features as well as on the geometry/size of the seams [3]. In particular, given the parent material, the most important technological variables affecting the quality of arc welded joints can be summarised as follows [4,5]: preparation of the parent material, welding current, welding voltage, welding speed, shielding gas, metallurgical characteristics of the filler material and number/sequence of passes.

The above parameters are important also from a structural integrity point of view. In fact, the overall static strength of welded joints depends not only on the weld bead's geometrical features, but also on the microstructural features of the

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Nomenclature

s	weld leg length
w, l, p, g, t	specimen's dimensions
E	Young's modulus
F	force
$F_{f,exp}$	experimental failure force
$F_{f,est}$	estimated failure force
K_{Ic}	plane strain fracture toughness
L	critical distance value
$Or\theta$	polar coordinates
$Oxyz$	Cartesian coordinates
S_D	standard deviation
T	specimen's reference thickness
κ	material constant linking σ_0 to σ_{UTS}
γ	local safety factor
σ_0	inherent material strength
σ_{eff}	effective stress
σ_{eq}	equivalent stress
σ_y	yield stress
σ_x, σ_y	local normal stresses
σ_{UTS}	ultimate tensile stress
σ_{VM}	Von Mises's equivalent stress
θ_f	fracture angle
τ_{xy}	local shear stress

material in the vicinity of the seams themselves (especially the heat-affected zone) [6,7]. Further, in conventional fillet welded joints subjected to uniaxial static loading, cracks are seen to initiate at the weld roots, subsequently propagating mainly through the weld beads [8]. This cracking behaviour suggests that, to efficiently control the overall strength of fillet arc welded joints, the technological variables must be set so that an adequate level of penetration can always be reached [9].

From a stress analysis point of view, if the parent and filler materials are assumed to obey a linear-elastic constitutive law, the stress fields in the vicinity of the weld roots are invariably singular [10], this holding true also in the presence of fabrication gaps [9]. In order to overcome the problem of handling singular stress fields without missing the undoubted advantages of linear-elastic stress analyses, existing design methods are based on the use of nominal stress quantities calculated with respect to a nominal weld throat area determined according to a variety of different geometrical rules [3,11,12]. Further, in order to correctly take into account the degree of multiaxiality of the applied systems of external forces and moments, the corresponding nominal stress components are combined together through empirical formulas which are derived either from the maximum principal stress criterion or from von Mises equivalent stress [11].

Although effort is being made to develop new optimised technological solutions [6], examination of the state of the art [13] suggests that available methods for designing welded joints against static loading are still based on the use of conventional nominal quantities, the reference document being the report published by the International Institute of Welding (IIW) back in 1968 [14]. The main limitations in efficiently using nominal quantities to address problems of practical interest can be summarised as follows: by nature, nominal stresses cannot directly be linked to the intrinsic quality of the manufactured weldments; in the presence of complex geometries, nominal stresses are poorly related to the actual stresses present in the critical areas of the weld that determine the overall static strength of the welded connections being assessed [15]. Further, whilst the aforementioned nominal stress based approaches can be used to perform a conventional static assessment using classic solid mechanics concepts, unfortunately they are not suitable for being used to directly perform an efficient computer aided design (for instance, through the FE method). Lastly, the use of nominal dimensions to calculate the stress quantities of interest prevents the use of stress/strength analyses to optimise the welding variables by simultaneously taking into account the actual morphology of the material microstructure in the vicinity of the assumed crack initiation points.

In this complex scenario, the aim of the present paper is to formalise and validate a novel methodology suitable for designing arc welded joints against static loading by directly post-processing the linear-elastic stress fields damaging the material in the vicinity of the critical locations.

2. Fundamentals of the theory of critical distances

The Theory of Critical Distances (TCD) [16] takes as its starting point the assumption that the static strength of notched/cracked engineering materials can directly be estimated by post-processing the entire linear-elastic stress field acting on the material in the vicinity of the geometrical features being assessed. According to this idea, by changing the shape and size of