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RE-APPRAISAL ANALYSIS OF WELDED JOINTS: DEFECT-TOLERANCE APPROACH

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ABSTRACT

The term fracture is a vague word used to describe the condition of obsoleteness of a structure. For welded joints, this term could take several forms of definitions. Therefore, it is of great importance to define this term, within a certain servicability condition. This is due to the fact that the welding process will produce a monolithic state in the welded joints and that fracture initiation in even a minor part can lead to catastrophic consequences. Also, the fact that there is no welded defect-free structures, thus the designer has no option but to reside himself to the so-called defect-tolerance approach.

In a country which applies different schools of quality assurance, as for example, Egypt, unification of the different codes and specifications of welding industry, is required. This unification should lead to the evolution of the Egyptian code of practice and hence the Egyptian Welding Standards and Specifications. This task is to be carried out with the aid of the defect-tolerance approach, proposed and discussed in the present paper.

1. INTRODUCTION

An understanding of fracture mechanics of welded joints may be vital for design purposes. The designer should base his design within certain owner requirements. The owner wishes his structure to be reliable in service, despite the probable presence of defects, cracks and flaws caused in the fabrication process. Also, the owner would like repair and hence maintenance costs to be minimum. For the fabrication shop practice it would be most helpful to know the maximum size of constructional defect or flaw size which could be tolerated without jeopardizing the operational safety of the structure.

The welded structure is generally designed on considerations of static strength or a quasi-static strength under high amplitude but frequent loads. There are two well-known design approaches in current use. The

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first known as the fail-safe approach, i.e., the approach which considers the appearance of cracks to be the end of life. The second is known as the fail-safe approach, i.e., the approach which considers the crack propagation until critical crack size, or critical static strength is reached.

A mixture of both of the two approaches is proposed in Ref. [1 - 3] This approach has lead to the appearance of the working-life approach which in turn has lead to the appearance of the most recent approach known as the Fitness for purpose approach. Within the last approach, the general design concept may be derived on a basis of tolerable fabricating defect sizes. This approach carries with it the assumption that a defect should not be able to grow to catastrophic proportions in one inspection period. This part of the concept is considered to be one part of a modified fail-safe approach. Fracture mechanics technology is already used for the evaluation of the flaws on reliability of structure performance and the material sensitivity. The latter may lead to a definition of allowable flow or defect sizes within a design. Thus fracture mechanics techniques can be used to evaluate the life of a structure after the the crack has formed or flaw is defined. Therefore, the fitness for purpose design considerations is based on fracture mechanics technology applications, [2] .

Also, the fracture mechanics is currently used in the design of innovative welded structural joints such as in the field of offsore structures, and drilling rigs, [4] . Fracture mechanics enables the owner to identify the vulnerable areas of the welded structure and hence to conclude rationale and more accurate design methods, [5] .

Fracture mechanics is therefore the tool and the science which enables a designer, an owner and also a fabricator to tailor the joints to serve at an environment, made from a specific material, and fabricated with a known fabrication process and within a certain quality control standards. By this technique more reliable and possibly more economical welded structures could be designed, and fabricated.

2. DEFINITION OF FAILURE

Failure may differ one from another as regards to their significance in use [6] . The meaning of failure as used in the present analysis depends on the fracture criterion chosen.

3. OBJECTIVES AND EXPECTED BENEFITS

Cost effective control of the production of a welded joint in a welded structure requires methods to handle quantitatively the involved parameters. This assessment covers the following objectives:

1. Definition of the required service performance, e.g., loads, extreme and lowest service temperature and the general parameters which will give a quantitative measure of the performance of the weldment in service.
2. Methods of measuring the mechanical properties of the weldment and the quantity, size and the distribution of defect (if any).
3. Assessment of the available welding processes and consumables for making the weldment, and detailed specifications of the welding procedures to be utilized.

The establishment of correlation among these three areas, provides a rational and design specifications and fabrication procedures to balance the cost of a weldment against its quality, and to make decisions as to the extent to which present specifications and standards can be safely relaxed to reduce initial costs. Nevertheless, welded joints have to be designed and fabricated to high standards of quality to meet specific operational service requirements [7] .

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However, it becomes necessary in the present climate of economic stringency to examine the possibilities of effective savings in cost by the acceptance of deliberate tolerable-defects, i.e., reductions in quality standards. So, it is important to assess qualitatively and quantitatively the effects of the presence of such defects on the reliability of the welded joint to ensure that these still meet their essential minimum requirements[8] .

The prime objective of the present work is to provide:

1. A study of tolerable defect sizes based on the failure criteria discussed above.
2. The proposal of an appraisal of the requirement for various welded joints that the industry may be in need of.

The expected benefits on the other hand may be summerized as follows:

1. The study will show the need of creation of Egyptian Welding Standards and the Egyptian Welding Code of Practice.
2. The ability of the designer to handle innovative welded joints.

3.1. PROBLEM DEFINITION

There is a basic problem in identifying the quality assurance and the quality standards. This is due to the variety, in not only the principals, but in the methodolgy of the application itself. This stimulates from the discrepancies within the different schools of non-destructive inspection, currently applied within the Egyptian Welding Industrial Sector. If for example the product is to follow the German Welding Standards, thus it should be verified by the DIN Standards. If, however, the same product fabricated from the same material, but welded within the requirements of the Japanese Welding Standards, then the JIS Standards should be applied, and the same rules apply to the A.W.S. Standards and the British Standards.

As a result of the variation in the requirements of each of the above mentioned quality standards, the efficiency of both the welder, the inspector and of the product itself, will dramatically, be affected. The cost of production will be increased, the speed in the line of production will be decreased, and thus there is a need for the evolution of the Egyptian Welding Standards. By these standards, unification of the same product, material, and fabrication processes and quality standards for the Egyptian Code of Welding Practice, will serve in increasing the efficiency of welders and the cost of production will be minimized.

3.2 PROPOSED DEFECT-TOLERANCE APPROACH

In order to evaluate the defect tolerance, there are certain assumptions to be fulfilled. For example the reliability of the welded joint should be thouroughly defined and estimated to a certain probability level.

The parameters should be considered within a scheme of work which facilitate the estimation and the checking of the following:

1. The monitoring and the inspection intervals must be determined for the defective welded joint.
2. The time from the instant a crack or a defect has been discovered until remedial action could take place, Fig. 1 .
3. The failure rate, which must be determined within a risk of failure.
4. The risk of failure based on techno-economical considerations.

3.3. DEFINITION OF RISK OF FALLURE

The risk is a vague term in the sense that the structure will during functioning meet the chance of events which may in turn lead to bad consequences, e.g., extreme cases that may lead to the loss of the structure. The British Standards [8] defined the risk as, it is the combined effect of the occurrence of an undesired event and the magnitude of the consequences of that event. So, the operator should, and in many cases must know the extent of risk involved in activity in which the welded joint is to serve.

4 STRUCTURAL RELIABILITY OF WELDED JOINTS

Structural reiability is the probability that the strength or capability is in excess of load or demand, equation (1) and Fig.2.

$$R = P\ (\ C > D\ ) \tag{1}$$

Strength characteristics, depend on geometry, absolute size, and geometrical dimensions, defect tolerance limits, surface conditions and environmental conditions. These parameters make the results of appraisal of welded joints specifically designed to reflect the relevant performance of the material in the structure under the critical condition of failure for which the reliability analysis is to be made, may be of a complicated process [9 - 11] .

In the special case when C and D are normally distributed (acceptable for extreme leads) the random variable which denotes the reserve strength, M, will also follow normal, distribution, with the mean M = C - D and the variance, $V_M = S_C^2 + S_D^2$ [12] .

Equation (1) may therefore be expressed in the form shown by equation (2).

$$P_f = \phi[B_f] \tag{2}$$

where,

$$B_f = \frac{\bar{C} - \bar{D}}{\sqrt{S_D^2 + S_C^2}}$$

The reliability therefore can be expressed as:

$$R = 1 - P_f \tag{3}$$

For other frequency distributions of load and strength, equation (2) can be in its general form to be read as in equation (2).

$$P_f = \int_{-\infty}^{+\infty} P(D)\ .\ \int_{+\infty}^{D} P(C).\ dC\ \ .\ dD \tag{4}$$

Appendix A shows the relationship between defect-tolorance and the reliability of failure. From this appendix it may be concluded that the main difficulty in establishing reliability criteria is to give proper weight to the aspect of safety in relation to the economical objectives. However, already today reliability criteria based on probabilistic approaches are found within the Regulatory and Standard Bodies.

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5. DISCUSSION AND APPLICATIONS

Fig.3, shows the proposed analysis for re-appraisal of welded joints, while Fig. 4 gives schematic method for catagorization of welded joints. The purpose of quality control programs and maintenance procedures, including periodic inspection maintenance and periodic tests of welded joints, is to improve their safety and reliability in service. The ability to estimate, quantitatively, the reliability improvement, enables us to perform optimization studies for both quality control and maintenance procedures with respect to risk, minimum expected cost, or maximum utility. In addition to the need of probability densities, fracture mechanics plays an important role for achieving and establishing defects tolerance approach. The computer program for the determination of the proposed defect-tolerance is shown in Fig.5.

An assessment for some welded joints for which the current proposed analysis has been carried out for different risk values and different sizes. The material is assumed to be of grade E mild steel and welded manually with a constant average amperage of 180 amps. and mean welding velocity of 25 mm/sec. at an arc welding voltage of 25 volts. Of course, the variation in one parameter of these stated above will lead to variation in the results. However, the work is limited in this paper to the applications stated above, due to the limitation in the size of the material represented in this conference.

Table 1 summerizes the results obtained for different quality of welded joints based on data obtained from Refs.[2, 7 - 12] .

6. CONCLUSIONS

Applications of the proposed defect tolerance approach as a rationale in the appraisal analysis of welded joints lead to the following conclusions:

1. Unification of the different codes currently applied within the Egyptian Welding Industrial Sector, will ease in sorting out most of the confusion problems and hence increase the efficiency, and productivity of the welders.
2. There are still a lot of work to be done in the field of defect-tolerance approach, viz, effect of variation of welding characteristics and parameters on the reliability of the welded joints containing defects. Also, in the safety assurance or the quality control the relationship of the uncertainties in the load predictions, and the fabricated uncertainties is required to be established for defect sizes of different shapes and different orientations.

7. NOMENCLATURE

A	material parameter		
a	defect size,	a_c	critical defect size.
a_f	final crak length	a_I	initial crack length
B_f	safety index		
$C, \bar{C}$	strength and mean of strength distribution.		
C_p	crack propogation parameter		
$D, \bar{D}$	load and mean of load distribution.		
F	probability that one randomly chosen stress range will be smaller than o		
K	stress intensity factor.		
K_c	critical stress intensity factor.		

k_m	parameters depend on geometrical proparties of the weldes joint and the defect
N	cycles of life to failure.
n	cycles in stress spectrum .
P(C)	probability density function of C.
P(D)	probability density function of D.
P_f	probability of failure.
q	notch sensitivity parameter.
R	reliability
S_c	standard deviation of the variability of strength, distribution.
S_D	standard deviation of the variability of load distribution.
V_M	variable of strength and load distributions.
α	intercept of the stress spectrum relationship.
β	inverse of the slope of the stress spectrum relationship
γ	intercept of the response curve to failure.
δ	slope of the response curve to failure.
σ	stress range.

8. REFERENCES

1. Gurney, T.R., "Fatigue of Welded Structures," Cambridge University Press. 1968.
2. Burdekin, F.M., "Practical Aspects of Fracture Mechanics in Engineering Design.," 17 th John Player Lecture, Proceedings of the Institution of Mechanical Engineers, Vol. 195, 1981.
3. Guidance on some Methods for the Derivation of Acceptance levels for Defects in Fusion Welded Joints. British Standards Institution PD 6493, 1980.
4. Detail Design in Ships. Lloy's Register of Shipping, 1967.
5. Harrison, J.D., and Young, J.G., "The Acceptability of Weld Defects," Paper Read at the Royal Institution of Naval Architects, 1974.
6. Rashed, A.F. et.al" A Proposed Analysis for the Evaluation of the Defect-Detection Methods with Application to Welded Joints,". Marine Session of the American Society for Non-destructive Testing, Spring Conference, Orlande, Florida, 1983.
7. El-Gammal, M.M., "Statistical Procedures for the Evaluation of Fatigue life of Marine Structural Details," Journal of the Arab Maritime Transport Academy. January, 1983.
8. El-Gammal, M.M., "Proposition of Development of a Welding Structures Manual with Application and case Studies. Paper Read at 4th Annual Welding Symposium, Egyptian Welding Society, Faculty of Engineering, University of Alex., March, 1983.
9. El-Gammal, M.M., "Evaluation Analysis of Life of a Welded Structure: Risk Analysis Approach," Paper Read at 2nd. PEDAC Conference; Alex. Univ., Dec. 1983.
10. El-Gammal, M.M., and El-Shennawy, A.K. "Statistical Evaluation of Fatigue life of Welded Joints- A Theoretical Approach," QUALTEST-2 Conference, Dallas Texas, Oct. 1983.
11. El-Gammal, M.M. " Proposition for the Evolution of an International Manual on Design, Fabrication, Quality Assurance for Structural Welded Joints," Paper Submitted for QUALTEBS-3, Cincinnati , Ohio, Oct. 1984.

12. Committee on Fatigue and Fracture Reliability of the Committee on Structural Safety and Reiability of the Structural Division, "Fatigue Reliability; Quality Assurance and Maintainability", Proc. ASCE, Vol. 108, ST1, January 1982.

13. Kuhn, P., " Residual Static Strength in the Presence of Fatigue Cracks," AGARD, Advisory, Report 11, 1967.

14. Kanninen, M., et.al," A Study of Ship Hull Crack Arrester Systems," Final Technical Report, Hull Crack Arresters Systems, SSC-265, 1977.

APPENDIX A

ASSESSEMENT OF DEFECT-TOLERANCE APPROACH BASED ON PROBABILISTIC FRACTURE MECHANICS.

The intent of this Appendix is to highlight the different criteria of defect tolerance Appreaches to quality control. These approaches can be seen in detail in References [3-12] . The present approach utilizes the assumption that the welded structural joint will be subjected to a stationary and ergodic random stress process. The failure curve is based on equation (5).

$$N . \sigma^{\varepsilon} = \gamma \tag{5}$$

The crack or defect can be modelled on the bases of an estimated Stress concentration factor, K_t, for the elastic range of loading, by equation (6), [13] & [14].

$$K_t = 1 + k_w . C_m . \sqrt{a} \tag{6}$$

with

$$C_m = \frac{(2 . E_u)}{r . E} \quad \text{and } k_w = (1-2.a/w) \text{ for edge through thickness}$$

$$r = A/\left(\frac{1}{q} - 1\right)^2 \qquad k_w = \sqrt{\frac{(1-2.a/w)}{(1+2.a/w)}} \text{ for central through thickness defect.}$$

Statistically, the following are the relerant three variables for the case of a welded joint:

a) Stress range predictions may be based on an exponential cumulative probability distribution function of the form given by equation (7).

$$F(\sigma) = 1 - e^{-\beta.\sigma} \tag{7}$$

Equation (7) has been derived based on the assumption that the number of cycles in an applied stress spectrum is that of the form given by equation (8).

$$n = \alpha . e^{-\beta.\sigma} \tag{8}$$

b) Defect or Crack propagation parameter

The parameters defined in the Paris-Erdogam crack propagation equation are affected by material type, method of fabrication, method of heat treatment, environment, loading rate and frequency of loading. These parameters need to be defined and evaluated by regression analysis of stress intensity factor vs. crack propagation rate , $\frac{da}{dN}$. The failure equation described by equation (5) , can be recalled to be that proposed by equation (9) .

$$\gamma = (af^{1-\delta.m} - a_i^{1-\delta.m})/(1-\delta.m).C.f^{\delta.m} \qquad (9)$$

Investigations carried out, show that there is a strong correlation between C_p and δ indicating that a low C_p corresponds to a high δ and vice versa. The residual stress is found to be one of the effective parameters playing an importans role especially at fusion areas.

c) Welding Defects

Welding defects are in general the main causes of local change in the geometrical contours of the fabricated structure, which may lead to the appearance of sharp cracks or notches. It is recognized that in the way of stress raisers the local stresses can be increased to well above the average stress level. Obviously, it is at these places of high stress concentration that sharp notches and defects are particularily dangerous, i.e., there is the chance of creating a notch within a stress raiser, thus superimposing discontinuity effects. Welding defects should be categorized into main respective and distinctive types. The ones which could be tolerated must be statistically represented, e.g., by equation (10), and the ones which are not to be tolerated need not be defined here.

$$f(a) = \frac{1}{(Sa)} \cdot e^{-\left(\frac{a - am}{Sa}\right)^{\lambda}} \qquad (10)$$

where a_m ,λ and Sa are statistical parameters need to be defined for the distribution of the tolerable defect sizes.

Table (1)

$N = 10^7$ cycles to failure, $\delta = 3.0$

QUALITY class of welded joint from Ref [5]	$P_f = 50$ %				$P_f = 16$ %				$P_f = 2.5$ %				DEFECT TOLLANCE (mm)	q
	σ_D	σ_e	K_t	K_{th}	σ_D	σ_e	K_t	K_{th}	σ_D	σ_e	K_t	K_{th}		
W	33.0	37.0	5.31	25.4	29.0	32	5.50	22.0	25.0	28.0	5.72	19.2	14.0	0.884
G	39.0	43.0	4.60	29.5	33.5	38	4.74	26.0	29.0	33.0	4.93	22.7	9.0	0.860
F2	50.0	55.0	3.56	40.0	42.0	50	3.70	34.3	38.0	44.0	4.09	30.2	4.0	0.803
F	56.0	66.0	3.18	45.3	47.0	57	3.30	39.1	40.0	48.0	3.58	33.0	3.0	0.750
E	69.0	82.0	2.56	56.5	57.0	68	2.79	47.0	47.0	57.0	3.04	39.1	2.0	0.743
D	74.0	90.0	2.40	62.0	63.0	76	2.54	52.0	53.0	65.0	2.70	44.6	1.5	0.700
C	102.0	124.0	1.75	85.1	89.4	109	1.78	75.0	78.0	96.0	1.83	65.9	0.50	0.591
B	124	145.0	1.43	100.0	111.4	130	1.43	89.2	1000.0	117.0	1.43	80.3	0.25	0.515

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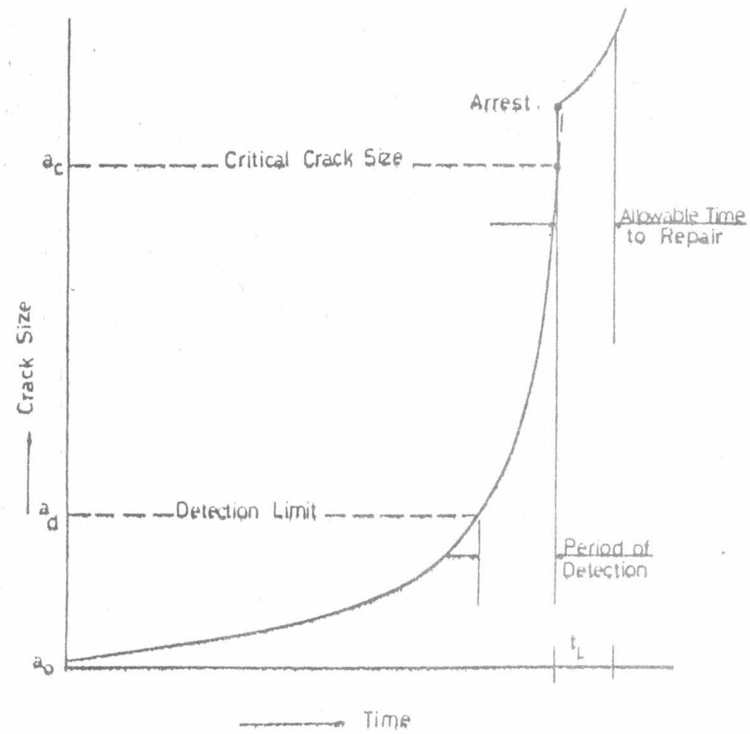

FIG.(1) CRACK GROWTH AND FAIL-SAFETY [After Ref.[14]]

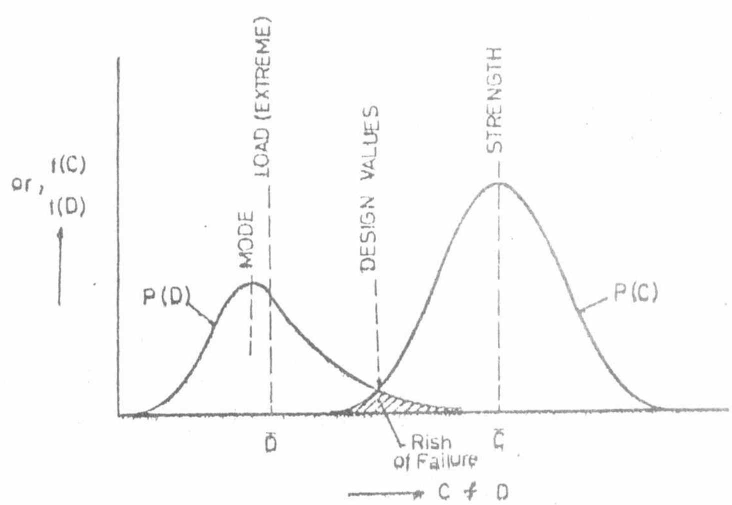

FIG.(2) DETERMINISDIC AND RELIABITY APPROACHES[11]

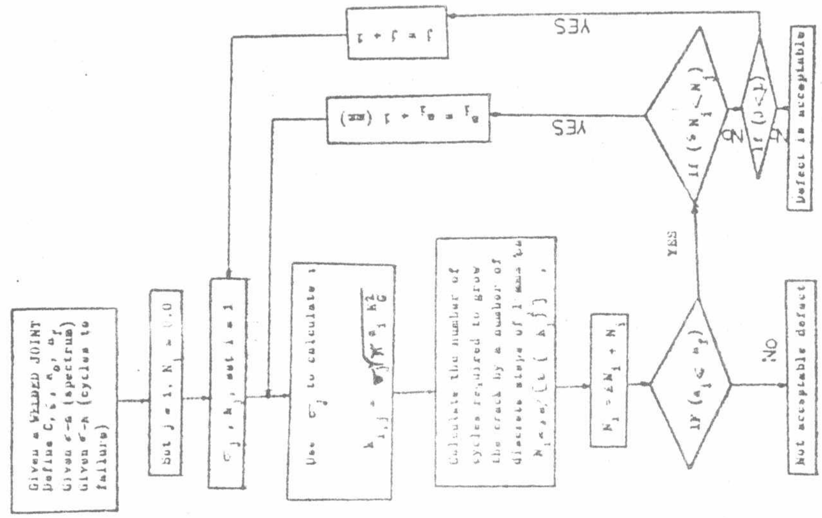

Fig. 3 RE-APPRAISAL ANALYSIS OF DEFECTS WITHIN WELDED JOINTS

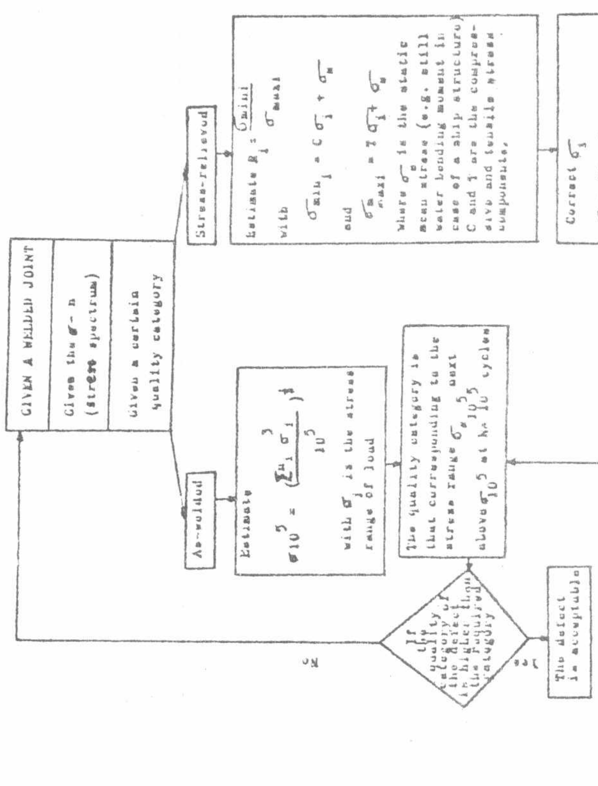

Fig. 4 : Schematic Categorization of Welded joint, based on Reference [3].

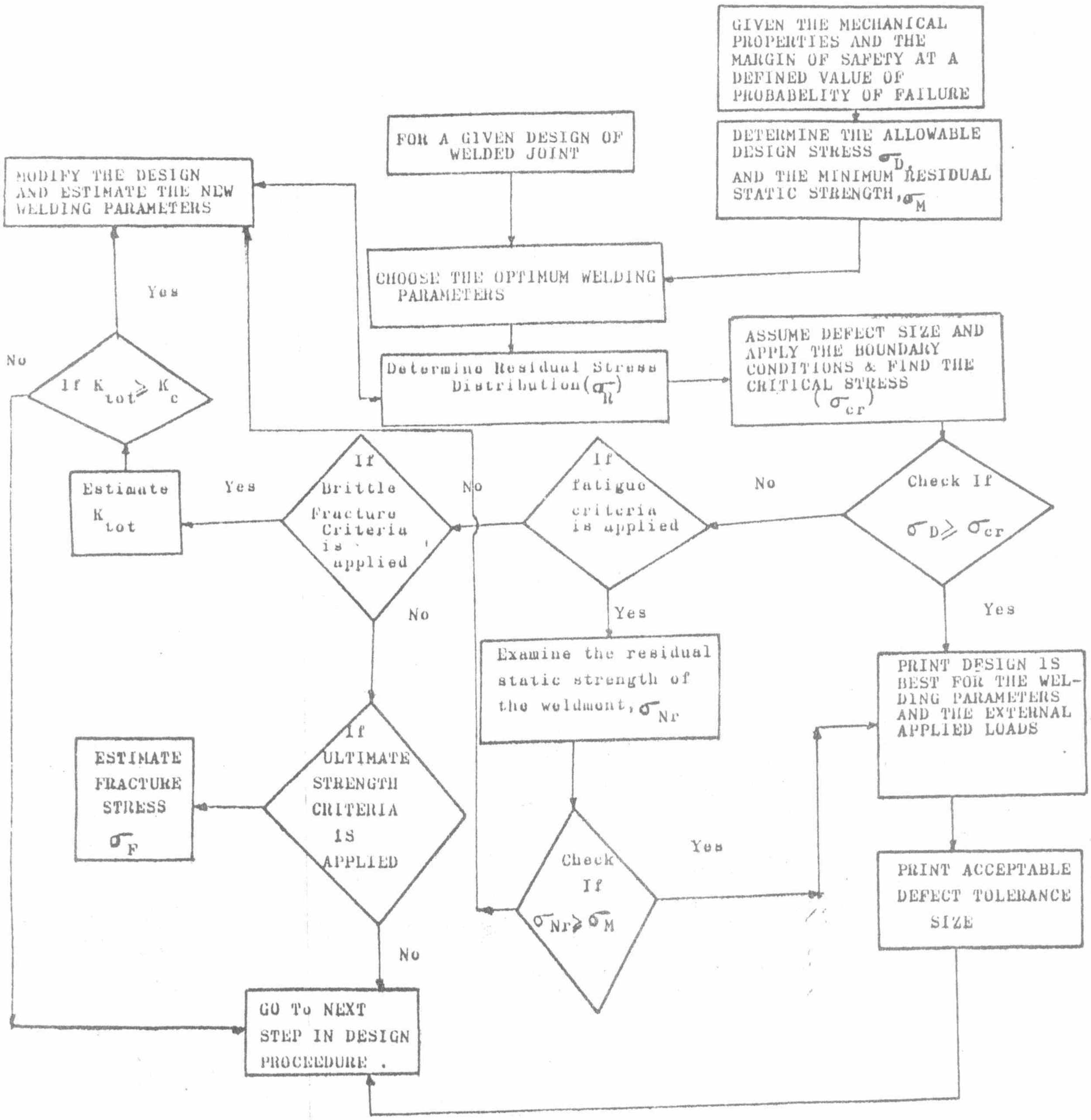

Fig. (5) : Flow Chart For The Computer Program For The Proposed Defect-Tolerance Approach.