FATIGUE CRACK GROWTH IN WELDED JOINTS PREPARED BY METHODS MMAW, SAW and GMAW (MAG)

RÝCHLOSŤ RASTU ÚNAVOVEJ TRHLINY ZVAROVÝCH SPOJOV VYHOTOVENÝCH METÓDAMI ROZ, ZPT a GMAW (MAG)

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Abstract

Paper summarizes result of achieved fatigue crack growth rates of separated steels and their welded joints prepared by MMAW, SAW and GMAW (MAG) methods.

Predložený príspevok zhrňuje výsledky rýchlosti rastu únavovej trhliny jednotlivých ocelí a ich zvarových spojov vyhotovených metódami ROZ, ZPT a GMAW (MAG).

Key words

crack, fatigue crack growth, remaining life, MMAW, SAW, GMAW, MAG, fitness-for-service

trhlina, rast únavovej trhliny, zvyšková životnosť, ROZ, ZPT, GMAW, MAG, vhodnosť pre daný účel

Introduction

This paper sets out the procedure for assessing the growth of planar flaws under fluctuating loading. It is based on a fracture mechanics analysis, which assumes that a flaw may be idealized as a sharp tipped crack which propagates in accordance with the law relating the crack growth rate, da/dN, and the range of stress intensity factor, ΔK, for the material containing the flaw. The basic steps of the procedure are shown in the flowchart in Fig.1.

The service life to date and the desired future service life should be defined. For the case of a component that was known to be flaw free at the start of operation, an estimate of the time at which the flaw formed should also be determined. The cause of cracking should be established to ensure that the fatigue crack growth procedure is applicable.

The component should be assessed against fracture initiation under fault or overload conditions at the initial flaw size using the fracture part of this procedure. This assessment should use the initial values of any residual stresses, not those in the shakedown state. If failure is conceded at this stage, the assumptions in the analysis should be revisited or remedial action take.

Calculate crack growth

The crack size at the end of the assessed period of operation is calculated by integrating the appropriate fatigue crack growth expression. This involves three sub-steps, which are repeated for pre-set cyclic increments: update the stress intensity factor as a function of the current flaw dimensions, compute the increment in crack size from the crack growth rate law, and check its stability at fault or overload load levels using the fracture procedure. The following paragraphs describe these for the Paris Law.

The following simple fatigue crack propagation law max be used in most cases:

$$da/dN = C\,(\Delta K)^m\,.$$

For all values ΔK below a threshold value, ΔK_o, the crack propagation rate is assumed to be zero. The values of C a m depend on material and environmental conditions and can be taken as constant over a limited range of ΔK only.

The choice of values for C a m should be based either on specific experimental results or on published data for the particular material being considered. Possible effects of temperature and a corrosive environment should be considered.

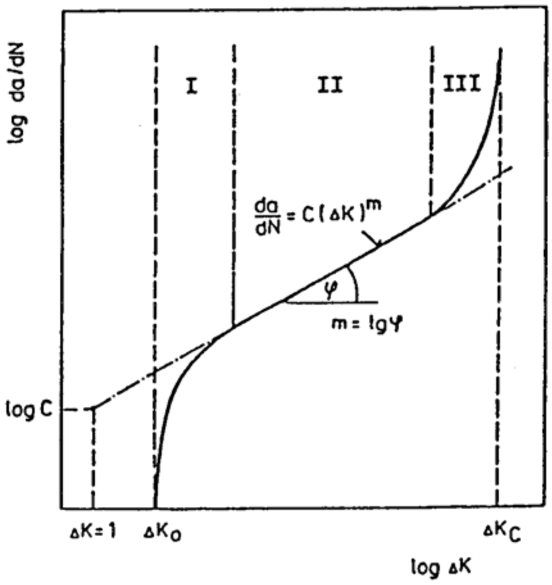

Fig. 1. *Schematic showing how the fatigue crack growth rate is represented by the Paris-Erdogan law (3)*

Remaining life evaluation

An estimate of the remaining life or limiting flaw size should be made for the purpose of establishing an inspection interval. The remaining life is established using the Fitness –For-Service assessment procedures with an estimate of future damage. The remaining life can be used in conjunction with an inspection code to establish an inspection interval.

The Fitness-For-Service assessment procedures in this recommended practice cover situations involving flaws commonly encountered in the refining and petrochemical industry in pressure vessels, piping and tankage. The procedures are not intended to provide a definitive guideline for very possible situation that may be encountered. However, flexibility is provided to the user in the form of an advanced assessment level to handle uncommon situation that may require a more detailed analysis.

In-Service Monitoring

Under some circumstances, the future damage rate/progression cannot be estimated easily or the estimated remaining life is short. In-service monitoring is one method whereby future damage or conditions leading to future damage can be assessed, or confidence in the remaining life estimate can be increased.

Characterization welding methods

Manual metal arc welding (MMAW)

Manual metal arc welding (MMAW) welding or informally as stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.

Manual metal arc welding is one of world’s most popular welding processes, accounting for over half of all welding in some countries. Because of its versatility and simplicity, it is particularly dominant in the maintenance and repair industry, and is heavily used in the construction of steel structures and in industrial fabrication. In recent years its use has declined as flux-cored arc welding has expanded in the construction industry and gas metal arc welding has become more popular in industrial environments. However, because of the low equipment cost and wide applicability, the process will likely remain popular, especially among amateurs and small businesses where specialized welding processes are uneconomical and unnecessary.

Gas metal arc welding (MAG)

Gas metal arc welding (GMAW), sometimes referred to by its subtypes, metal inert gas (MIG) welding or metal active gas (MAG) welding, is a semi-automatic or automatic arc welding process in which a continuous and consumable wire electrode and a shielding gas are fed through a welding gun. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Today, GMAW is commonly used in industries such as the automobile industry, where it is preferred for its versatility and speed. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility.

Submerged arc welding (SAW)

Submerged arc welding (SAW) is a high-productivity automatic welding method in which the arc is struck beneath a covering layer of flux. This increases arc quality, since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself and, combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes since the flux hides the arc and no smoke is produced. The process is commonly used in industry, especially for large products. As the arc is not visible, it requires full automatization. In-position welding is not possible with SAW.

SAW is a common arc welding process. It requires a continuously fed consumable solid or tubular (metal cored) electrode. The molten weld and the arc zone are protected from atmospheric contamination by being “submerged” under a blanket of granular fusible flux. When molten, the flux becomes conductive, and provides a current path between the electrode and the work. SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are available. The process is normally limited to the 1F, 1G, or the 2F positions (although 2G position welds have been done with a special arrangement to support the flux)(6).

Results

On these next figures (Fig. 2 - 5) are graphically shown results of fatigue crack growth rates for these variants of steels and their welded joints:
Fig. 2: Obtained results on base materials of steels. Fig. 3: Comparison of welded joints prepared by MMAW (MMA) method. Fig. 4: Comparison of welded joints prepared by GMAW (MAG) method. Fig. 5: Comparison of welded joints prepared by SAW method.

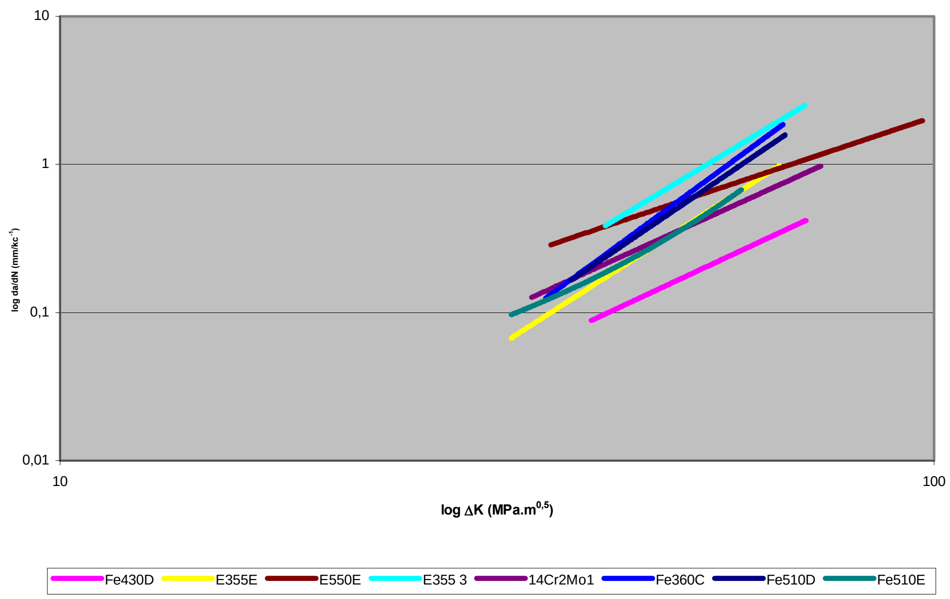

Fig. 2. *Comparison of separated steels (7, 8, 9)*

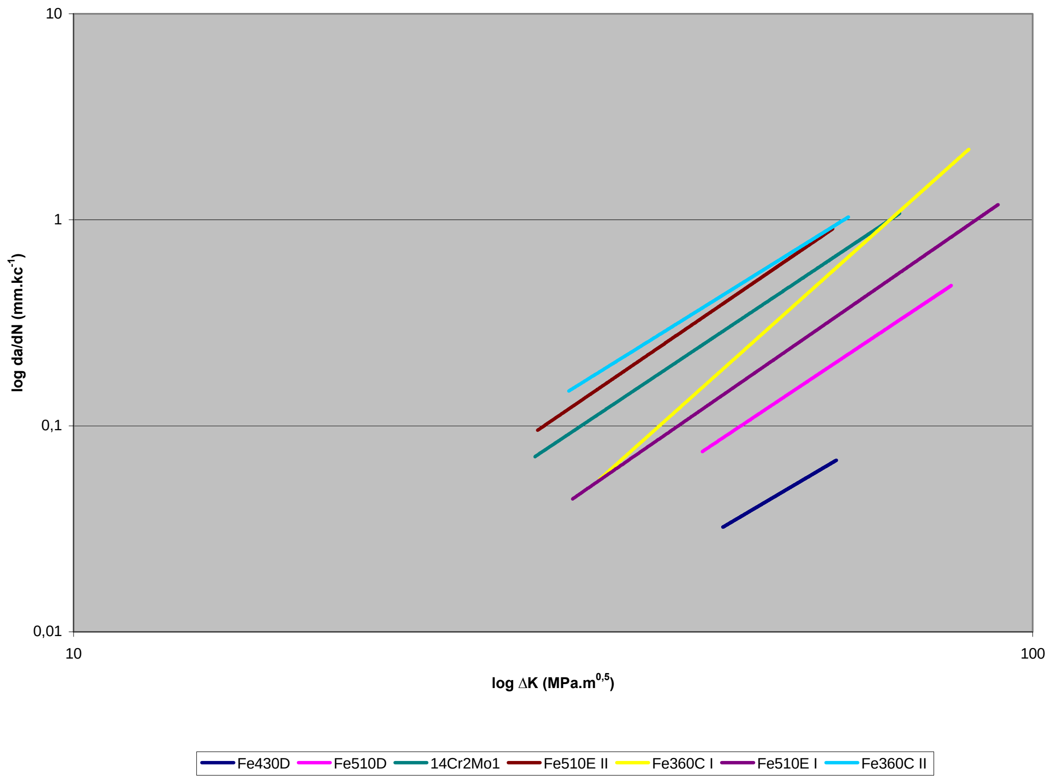

Fig. 3. *Comparison of welded joints prepared by MMAW method*
1) Fe430D – E - B 122, E – B 235; 2) Fe510D – E – B 124; 3) Fe360C – E – B 235; 4) Fe360C – E – B 235; 5) Fe510E – E – B 235; 6) Fe510E – E – B 235; 7) 14Cr2Mo1 – Chromo 2(7,8,9)

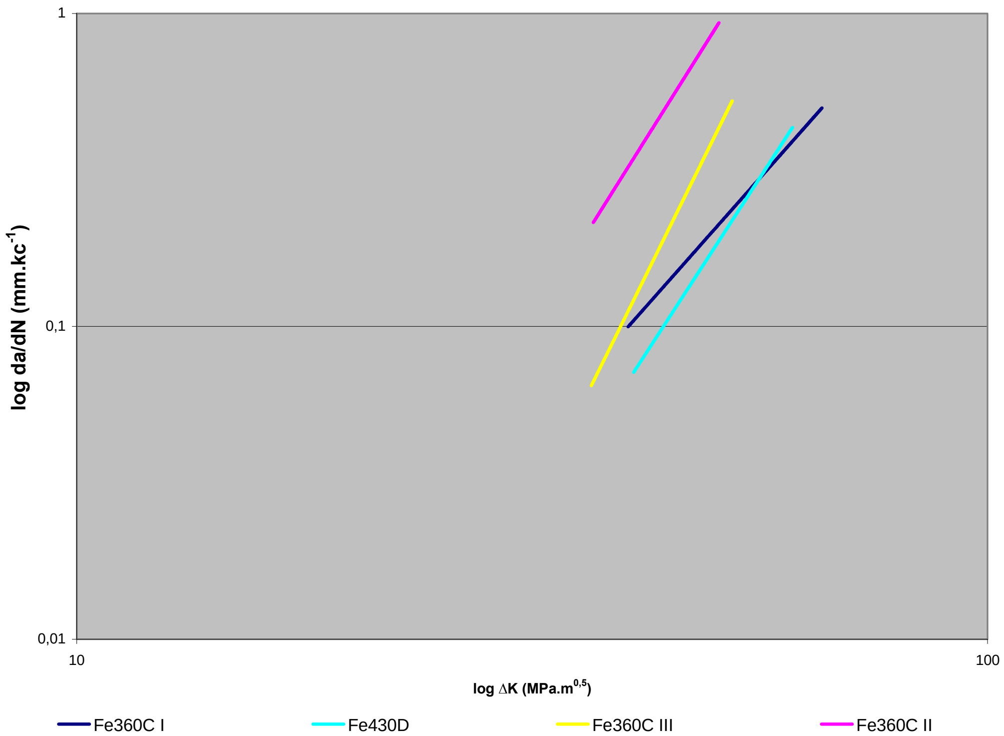

Fig. 4. *Comparison of welded joints prepared by GMAW (MAG) method*
1) Fe360C – wire: C133, gas: Ar+CO_2; 2) Fe360C, wire: C133, gas: Ar+CO_2; 3) Fe360C,wire: C133, gas: Ar+CO_2; 4) Fe430D, wire: C133, gas: CO_2. (7,8,9)

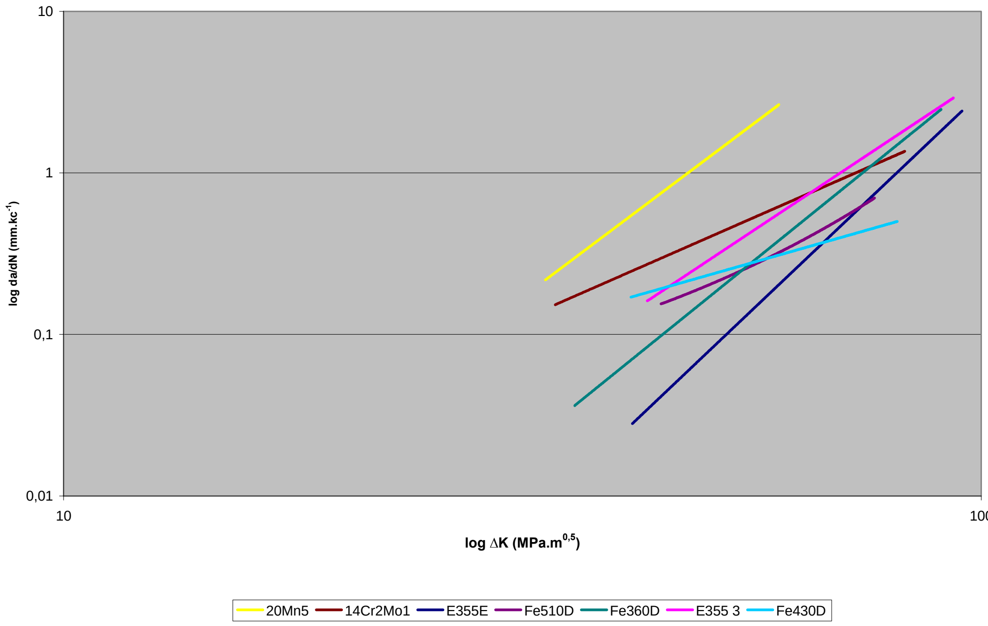

Fig. 5. *Comparison of welded joints prepared by SAW method*
1) E355E –flux: FK490, wire: A234; 2) E355E – flux: FK490, wire: A234; 3) 20Mn5 – flux: F102 + F103 (1:1), 4) Fe430D – flu: VÚZ N70, wire: A 234; 5) Fe510D, flux: F103, wire: A106; 6) 14Cr2Mo1, flux: UV 420TTR, wire: S1CrMo2. (7,8,9)

Presented results were obtained during experimental research of authors and at solving of research projects (VEGA, APVT) and relate to PhD thesis.

Discussion

Present paper gives a summary result of achieved fatigue crack growth rate of steels and their welded joints prepared by MMAW, SAW and GMAW (MAG) methods.

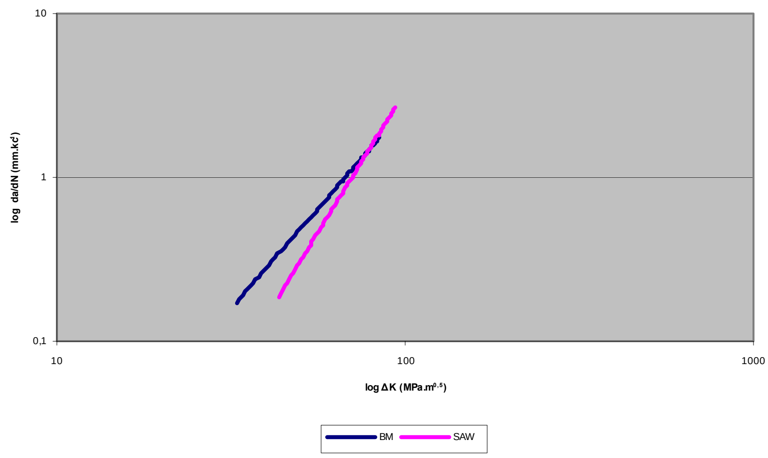

Fig. 6. *Comparison of fatigue crack growth rate of base metal E 355 3 and welded joint SAW (7,8,9)*

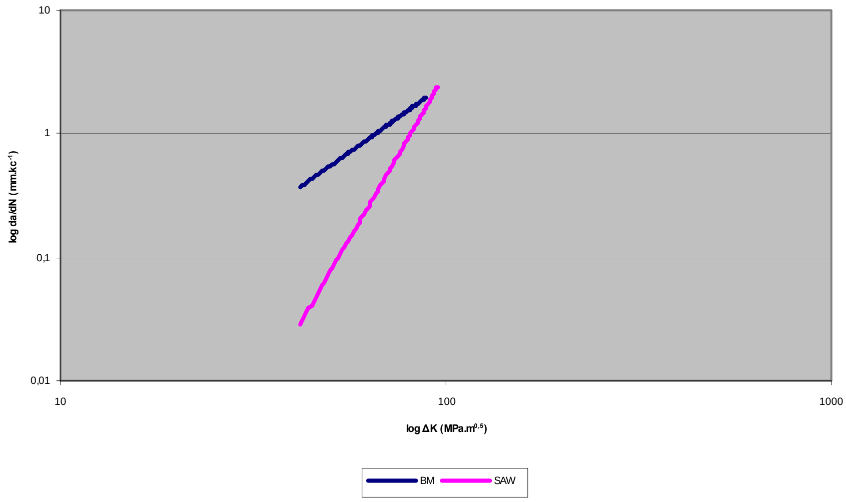

Fig. 7. *Comparison of fatigue crack growth rate of base metal E 355 E and welded joint SAW (7,8,9)*

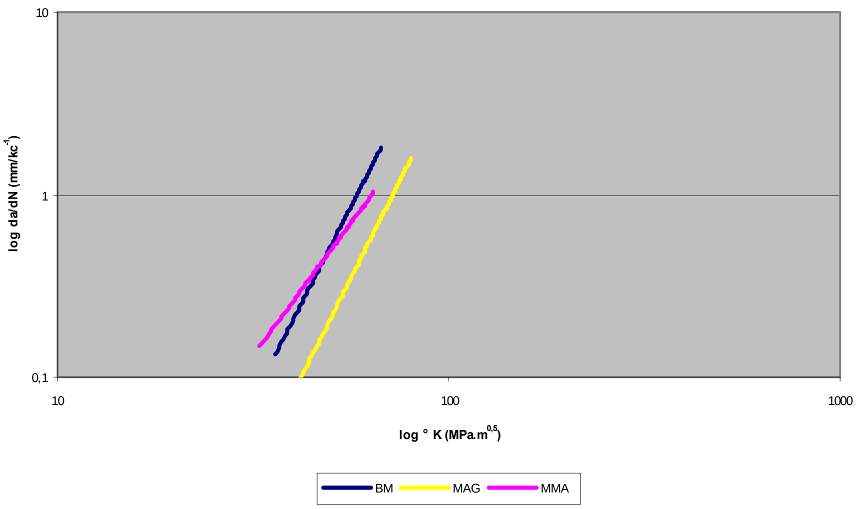

Fig. 8. *Comparison of fatigue crack growth rate of base metal Fe 360 C and welded joints MMAW, GMAW (MAG) (7,8,9)*

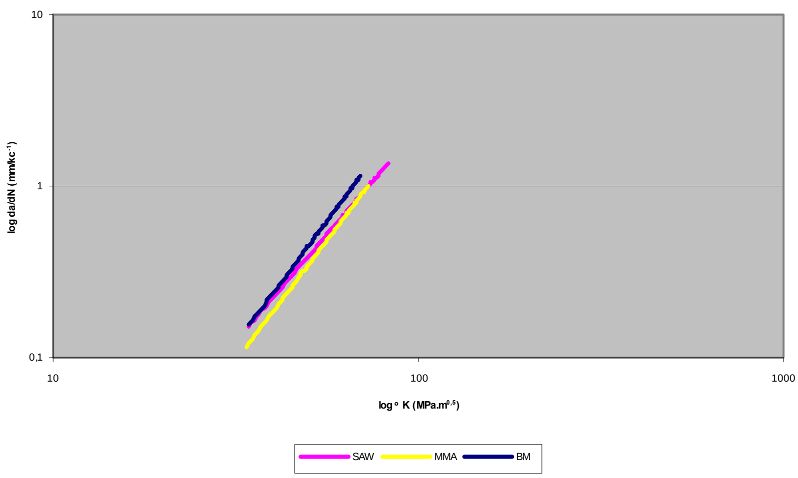

Fig. 9. *Comparison of fatigue crack growth rate of base metal 14Cr2Mo1 and welded joints MMAW, SAW (7,8,9)*

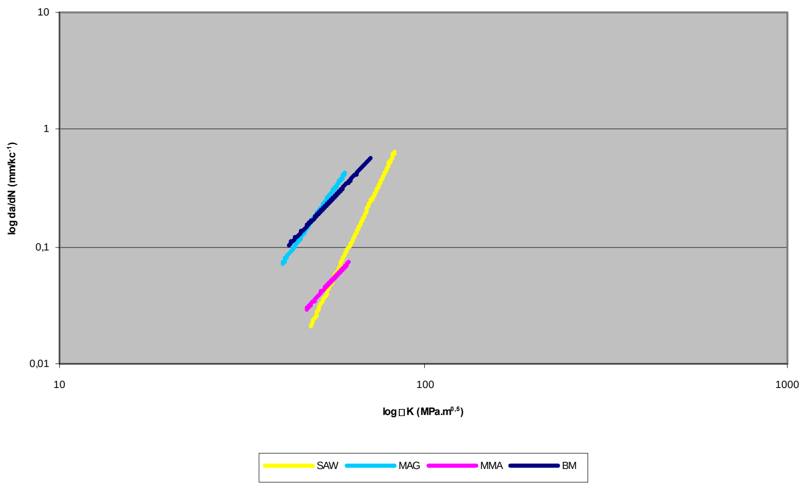

Fig. 10. *Comparison of fatigue crack growth rate of base metal Fe430D and welded joints MMAW, GMAW (MAG), SAW (7,8,9)*

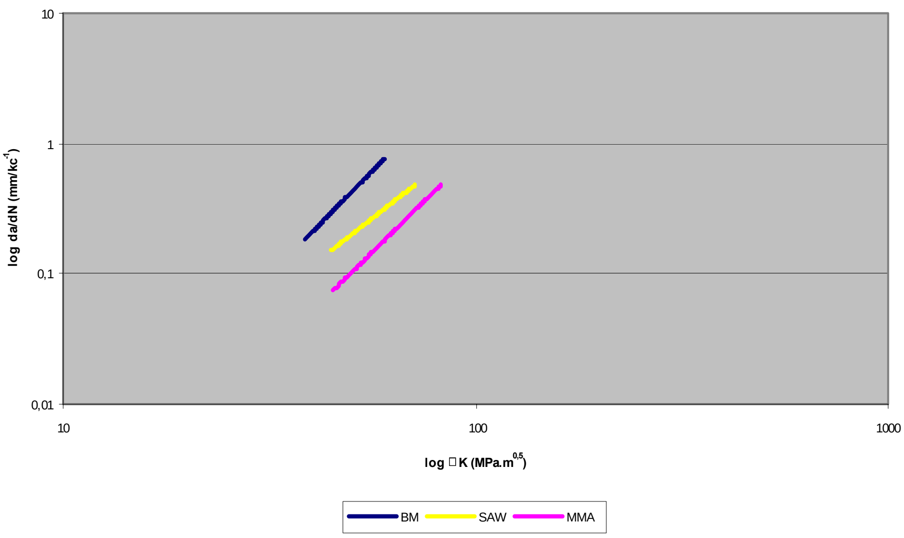

Fig. 11. *Comparison of fatigue crack growth rate of base metal Fe510D and welded joints MMAW, SAW (7,8,9)*

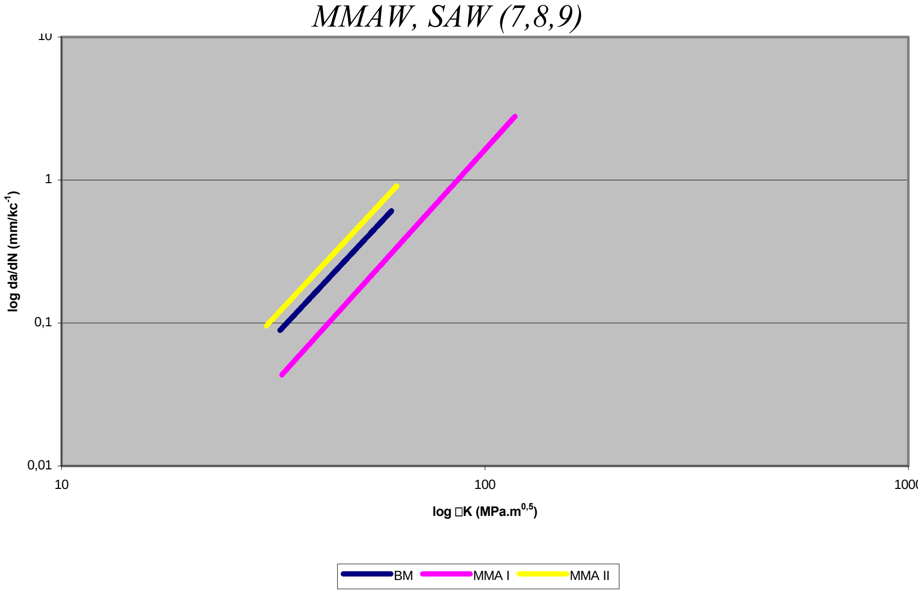

Fig. 12. *Comparison of fatigue crack growth rate of base metal Fe510E and welded joints MMAW I, MMAW II (7,8,9)*

From the experimental results could be derived, that prevailing part of tested variants the fatigue crack growth rate is bigger on base metal as in welded joints. The explanation of this effect could be the strength of tested variants. Generally the welded joints strength is higher than in base metal. That could be the reason of decreasing of fatigue crack growth rate in weld metal. Only one exception of this effect is for one variant of MMAW welded joint, fig. 12. In this case the strength of weld metal was higher than in base metal.

Conclusion

Fitness-For-Service analysis should be used by projection of welded constructions and also by residual life estimation. Documentation requirements specific to a particular assessment are described in the corresponding section covering the FFS assessment procedure. The following items should be included in the documentation.

The equipment design data, and maintenance and past operational history to the extent available should be documented for all equipment subject to a FFS assessment.

Inspection data including all readings utilized in the FFS assessment.

Assumptions and analysis results including:

- Section, edition, and analysis level of this document and any other supporting documents used to analyze the flaw or damage.
- Future operating and design conditions including pressure, temperature and abnormal operating conditions.
- Calculations for the minimum required thickness.
- Calculations for remaining life and the time for the next inspection.
- Any mitigation/monitoring recommendations that are a condition for continued service.

This paper was worked out within solution of project VEGA 1/2068/05 (VEGA 720) "Estimation of acceptability of cracks in fusion-welded joints".

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