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Expert system approach for nuclear piping integrity

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ABSTRACT: The objective of this paper is to develop expert system called NPiES(Nuclear piping Integrity Expert System) for nuclear piping integrity. This paper describes the structure and development strategies of NPiES system. NPiES system is consisted of 5 parts; database, knowledge base, inference engine, integrity evaluation and utilities. Nuclear piping material properites are stored in the database and various rules recommended by Code & Standard are stored in the knowledge base. Unavailable material properties are inferred in the inference engine using NEXPERT Object through inferring the given material properties. In the integrity evaluation part, various evaluation methods such as LEFM, EPFM, limit load method and fatigue analysis are provided.

1. INTRODUCTION

The expert system, as part of artificial intelligence(AI), is being applied for the purpose of design and diagnostic analysis in a variety of engineering fields. In nuclear industry, applications of AI technology to the integrity assessment of power plant facilities have been progressed from early 80's and several softwares such as ESR(Jovanovic, 1991), RAMINO(Lucia and Volta, 1991) and DIAS(Okamodo, et al, 1987) have been developed.

The objective of this paper is to develop expert system called NPiES(Nuclear piping Integrity Expert System) for nuclear piping integrity. Main attraction of the system is obtaining unknown material properties through material property inference. In a majority of integrity evaluation systems currently being used, unless all material properties required for the integrity evaluation are fully provided, integrity analysis cannot be processed. However, as shown in Fig.1, various options are available to overcome this problem in NPiES system. Also the most appropriate integrity evaluation method corresponding to the input conditions is selected based on both the ASME Sec.XI procedure and the possession ratio of material property. This paper describes the structure and development strategies of NPiES system.

2. STRUCTURE OF NPiES SYSTEM

NPiES system is consisted of 5 parts; database, knowledge base, inference engine, integrity evaluation and utilities. The system was developed under Windows 3.1 environment and the structure of the system is shown in Fig.2.

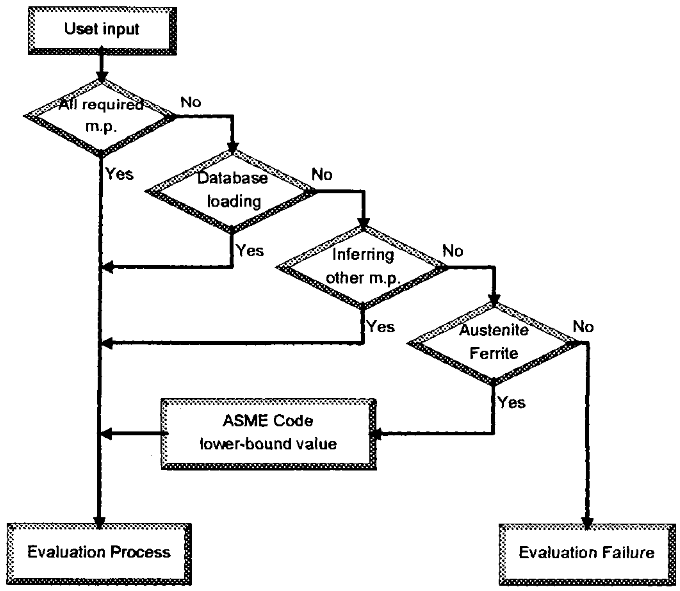


Fig.1 Flow chart for obtaining material properties in NPiES system

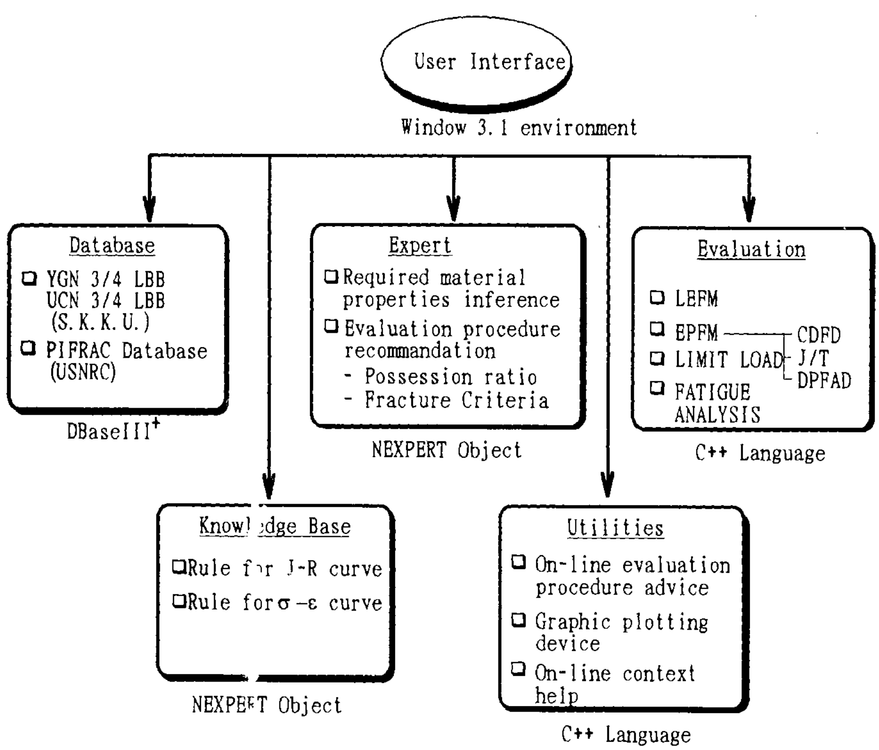
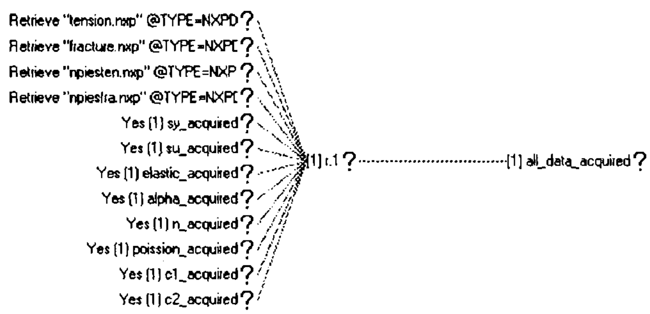


Fig. 2 Structure of NPiES system

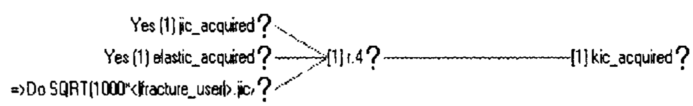
NPiES system has material property(tensile and fracture toughness) database for nuclear piping steels such as SA304, SA312, SA508, SA106 etc. A majority of test data was obtained from domestic material test program such as Yonggwang 3/4 LBB(Kim et al 1993) with additional information obtained from literature survey. Various material constants such as Ramberg-Osgood parameters are directly provided, or can be obtained by curve-fitting the raw data for proper range. An effective database management system was constructed by utilizing DBase III$^+$.

In the knowledge base, the following steps are taken to obtain necessary material properties.

Step 1 : Obtain material property by searching the material property database.



Step 2 : Obtain material property by inferring given material properties.



Step 3 : Obtain lower-bound material property given in ASME Sec.XI depending on austenitic and ferritic steels.

In the expert part, required material properties for the analysis are inferred and a proper integrity evaluation method for given input conditions is recommended.

In the evaluation part, four evaluation methods such as LEFM, EPFM(CDFD, J/T, DPFAD), limit load method and fatigue analysis are provided for the purpose of piping integrity evaluation. This part is developed in object oriented programming using C^{++} language and is modulized for the sake of easy expansion of the system.

In the utility part, proper explanation, diagnosis and recommendations are provided for evaluating the input data, calculation procedure and analysis results.

3. SENSITIVITY ANALYSIS OF EVALUATION METHOD

3.1 Sensitivity analysis

In order to quantitatively determine the effect of improper input meterial data on the analysis results, sensitivity analysis of the integrity evaluation methods (limit load method and J/T method) were performed.

Governing material property in the limit load method is flow strength(S_f) which is defined as average value of yield strength(Sy) and ultimate tensile strength(Su). Fig.3(a) shows the variation of limit load as a function of material sensitivity in the limit load method. As shown in the figure, the sensitivity due to the variation of Su value is higher than that due to the variation of Sy value.

Accordingly the weight factor for respective material property is defined as given in Table 1.

Table 1 Weight factor for limit load method

Mat. Property	Sy	Su
Weight Factor(%)	30	70

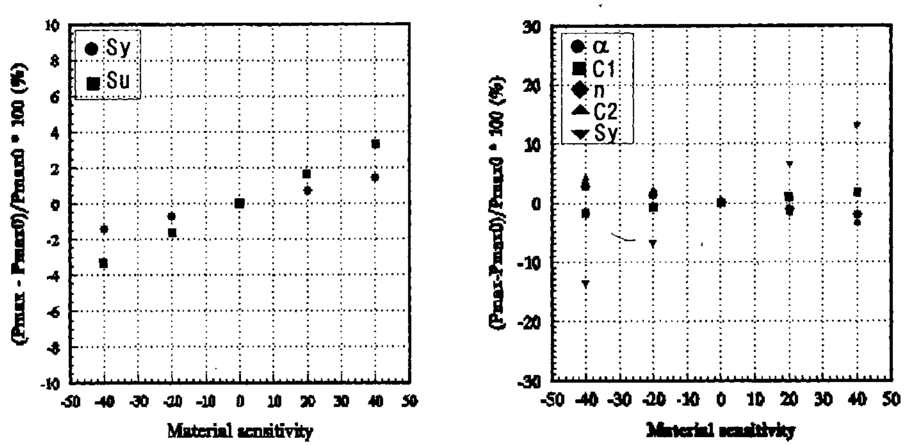
Governing material properties in the J/T analysis are;

- Ramberg-Osgood constants ; α,n
- Reference stress in Ramberg-Osgood curve ; Sy
- Material constants of J-R curve ; C_1, C_2

Fig.3(b) shows the variation of maximum load as a function of material sensitivity in the J/T method. As shown in the figure, the Sy value is the dominant factor, and the respective weight factor for respective material property defined as given in Table 2.

Table 2 Weight factor for J/T method

Mat. Property	α	n	Sy	C_1	C_2
Weight Factor(%)	9	14	56	7	14



(a) limit load method (b) J/T method

Fig. 3 Sensitivity analysis results

3.2 Selection of evaluation method

In order to perform integrity evaluation, the most appropriate evaluation method for given input information such as material property, operating condition, piping and defect geometry is selected based on following two rules.

1) ASME Sec.XI procedure
2) Possession ratio of material properties

3.2.1 ASME Sec.XI procedure

In ASME Sec.XI, evaluation procedures for austenitic and ferritic piping materials are given. The austenitic piping material is distinguished between austenitic materials with high fracture toughness and certain flux welds that have lower toughness. The base metal and non flux weld(GTAW,GMAW) evaluation is based on a plastic collapse failure mechanism and the allowable flaw sizes were generated from the limit load analysis. The flux weld evaluation is based on an unstable crack tearing failure mechanism and the allowable flaw sizes are determined using EPFM analysis methods.

The ferritic piping material is distinguished by high toughness materials(base metal) and certain lower toughness flux welds, which include shielded metal arc welds(SMAW) and submerged arc welds(SAW). Because the predicted failure mechanism for the flux welds was unstable flaw extension that would occur at loads lower than the plastic collapse analyses. The applicable failure mode is defined depending on material toughness, load type and magnitude, and flaw size, shape and orientation, and an appropriate evaluation method is recommended.

3.2.2 Possession ratio of material properties

The possession ratio of material property is computed based on the previously obtained weight factor. Fig.6 shows an example for computing the possession ratio. Assume that α, n, Sy, C_1, C_2 values are required for the analysis, and α, n, Sy values are only given. If the material inference is failed, the current possession ratio is computed as following:

- Possession ratio = weight factor for α(9%) + n(14%) + Sy(56%) =79%

If the inference is successful, the weight factor is redefined by multiplying the weight factor and the certainty of rules and the possession ratio is recomputed as following:

- Redefinition of weight factor for C_1= 7* 0.7(70%) = 4.9
- Redefinition of weight factor for C_2= 14* 0.9(90%) = 12.6
- Possession ratio = α(9%) + n(14%) + Sy(56%) + C_1(4.9%) +C_2(12.6%) =96.5%

After obtaining the possession ratio of material property for respective integrity evaluation methods, the method which has the highest possession ratio is recommended.

4. INFERRING UNKNOWN MATERIAL PROPERTIES

Although the tensile properties are easily found in open literature, the material constants C_1, C_2 of full J-R curve are seldom found. The following empirical equation was obtained by statistically correlating the tensile data and J-R data(Kim et al,1995).

(1) $$C_1 = 2250Ek(S_u^{'} \times \sqrt{\varepsilon_c})^{2.201}$$

(2) $$C_2 = 0.4 \sim 0.6$$

where E is Young's modulus, k is non-dimensional constant, Su' is the defined as Su/E and ε_C is fracture strain.

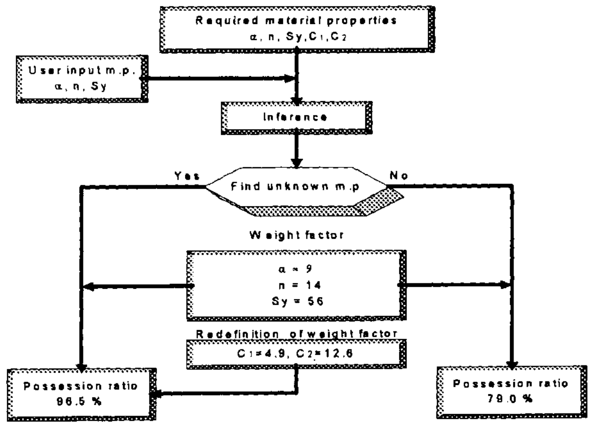


Fig. 4 Flow chart for computing possession ratio

When the σ-ε curve is unknown, Ramberg-Osgood constant α is obtained from following equations.

(3) $$\frac{\sigma_u}{\sigma_y}\frac{2.7183^{1/n}}{1.002+\sigma_y/E}=\{\frac{1/n}{\ln(1.002+\sigma_y/E)}\}^{1/n}$$: EPRI

(4) $$\frac{\sigma_u}{\sigma_y}(1.002+\varepsilon_0)=\{n\times 2.718\ln(1.002+\varepsilon_0)\}^{1/n}$$: FRAMATOME

and the n value is obtained from following equations.

(5) $$\alpha=\frac{1}{\sigma_y/E}\times\{\frac{\ln(1.002+\sigma_y/E)^{1/n}}{(1.002+\sigma_y/E)}\}^n$$: EPRI

(6) $$\alpha=\frac{E}{2.7183n\sigma_0}(\frac{\sigma_0}{\sigma_u})^n$$: BATTELLE

(7) $$\alpha=\frac{(1/\varepsilon_0)\ln(1.002+\varepsilon_0)-1.002-\varepsilon_0}{(1.002+\varepsilon_0)^n}$$: FRAMATOME

where σ_0 is reference stress, ε_0 is defined as σ_0/E.

In addition, various rules for inferring J_{IC}, K_{IC}, S_y values are also stored in the knowledge base.

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