Summary of Contributions to the "FAD-CDF Compatibility" and "Y/T" Working Groups

UNIVERSITY OF CANTABRIA

Report/SINTAP/UC/08

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1. INTRODUCTION

This Report summarises the University of Cantabria's contributions to *the "FAD-CDF compatibility"* and *"Y/T" Working Groups* led by Nuclear Electric and British Steel respectively which have been developed during the last months within SINTAP.

Hence, the last UC's reports [Report/SINTAP/UC/05, 06 and 07] are collected here. This compendium is not only a summary of UC's developments but also is intended to show the main ideas needed to develop a Final Report by British Steel.

2. EQUATIONS FOR SINTAP PROCEDURE

2.1. LEVEL 1: BASIC

Failure assessment Line

No Lüders Strain Expected

$$K_r = \left[1+\frac{L_r^2}{2}\right]^{-1/2}\left[0.3+0.7\exp(-0.6L_r^6)\right] \tag{1}$$

Lüders Strain Expected

$$K_r = \left[1+\frac{L_r^2}{2}\right]^{-1/2} \tag{2}$$

Crack Driving Force

No Lüders Strain Expected

$$J = \frac{K_I^2}{E'}\left[1+\frac{L_r^2}{2}\right]\left[0.3+0.7\exp(-0.6L_r^6)\right]^{-2} \tag{3}$$

Lüders Strain Expected

$$J = \frac{K_I^2}{E'}\left[1+\frac{L_r^2}{2}\right] \tag{4}$$

2.2. LEVEL 2: ASSUMED N

Failure assessment Line

No Lüders Strain Expected

$$K_r = \left[1 + \frac{L_r^2}{2}\right]^{-1/2} \left[0.3 + 0.7\exp(-\mu L_r^6)\right] \quad \text{(for } L_r < 1\text{)} \tag{5}$$

$$\text{where } \mu = \min\left[0.001\left(\frac{E}{YS}\right); 0.6\right] \tag{6}$$

$$K_r = K_{r(L_r=1)} L_r^{\frac{\tilde{N}-1}{2\tilde{N}}} \quad \text{(for } L_r \text{ □ } 1\text{)} \tag{7}$$

$$\text{where } \tilde{N} = 0.3\left(1 - \frac{YS}{UTS}\right) \tag{8a}$$

(see Annex)

$$\tilde{N} = 0.3 - \frac{1}{3}\frac{YS}{UTS} \quad \text{(for } \frac{YS}{UTS} < 0.9\text{) and } \tilde{N} = 0 \quad \text{for (}\frac{YS}{UTS} \text{ □ } 0.9\text{)} \tag{8b}$$

Lüders Strain Expected

$$K_r = \left[1 + \frac{L_r^2}{2}\right]^{-1/2} \quad \text{(for } L_r < 1\text{)} \tag{9}$$

$$K_r = \left[\lambda + \frac{1}{2\lambda}\right]^{-1/2} \quad \text{(for } L_r = 1\text{)} \tag{10}$$

$$\text{where } \lambda = 1 + \frac{E\Delta_\varepsilon}{YS} \tag{11}$$

$$K_r = K_{r(L_r=1)} L_r^{\frac{\tilde{N}-1}{2\tilde{N}}} \quad \text{(for } L_r \text{ □ } 1\text{)} \tag{12}$$

Crack Driving Force

Following the general transformation between Failure Assessment Lines and Crack Driving Forces, we can obtain the equivalent equations:

$$J = \frac{K_I^2}{E'}\left[f(L_r)\right]^{-2} \tag{13}$$

2.3. LEVEL 3: MEASURED N

Failure assessment Line

$$K_r = \left[\frac{E\varepsilon_{ref}}{L_r\sigma_y} + \frac{L_r^3\sigma_y}{2E\varepsilon_{ref}} \right]^{-1/2} \tag{14}$$

Crack Driving Force

$$J = \frac{K_I^2}{E'} \left[\frac{E\varepsilon_{ref}}{L_r\sigma_y} + \frac{L_r^3\sigma_y}{2E\varepsilon_{ref}} \right] \tag{15}$$

ANNEX: A SAFETY ESTIMATION OF Ñ

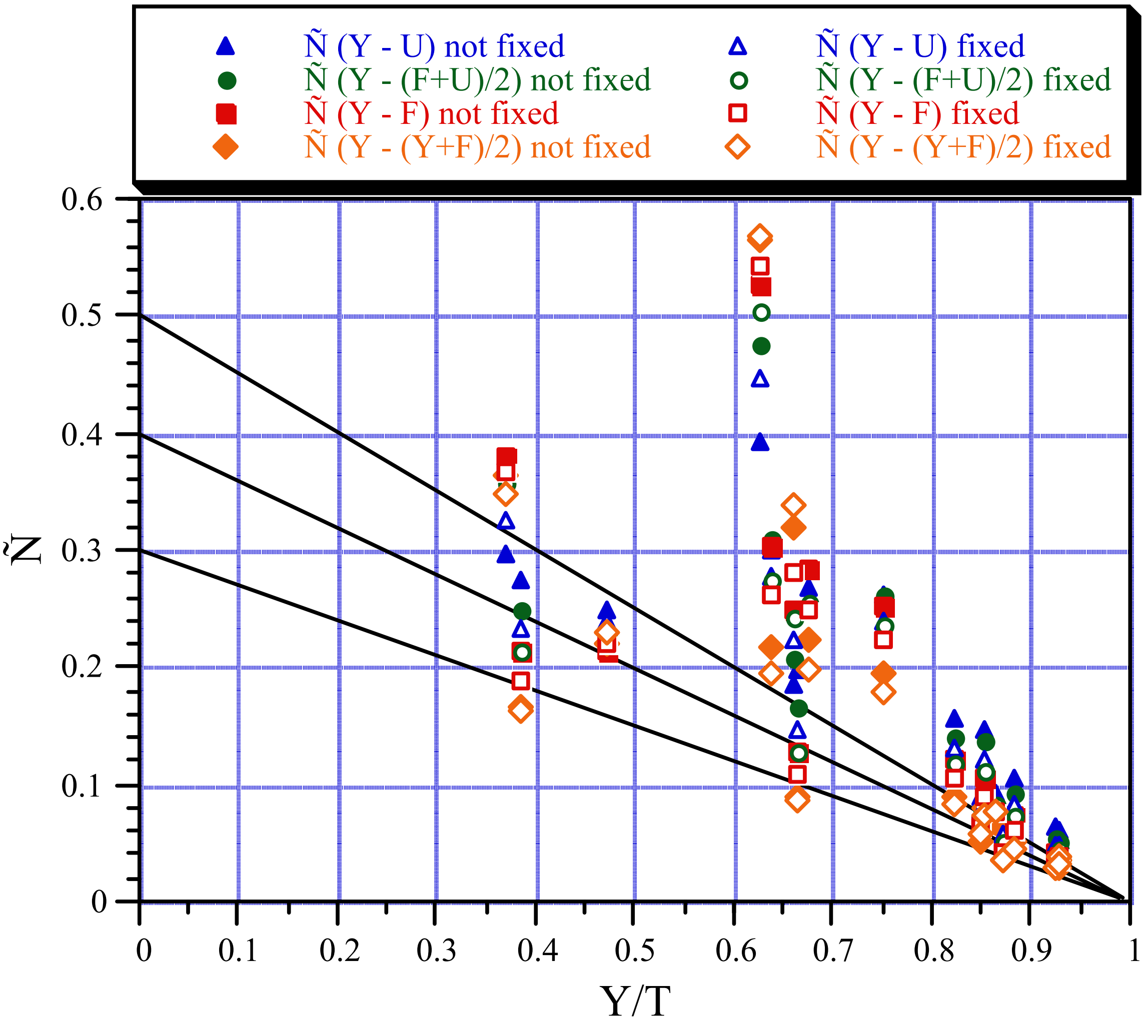
In Report/SINTAP/UC/07, different type of calculations were performed in nineteen materials. The intention of such analysis was to assure a safety estimation of the parameter N used in several of the Procedure's equations. All that calculations were done with real values and concerning strain data, only total values were considered.

It was decided to complete the study performing the calculations with **plastic strain data**. This annex present such results.

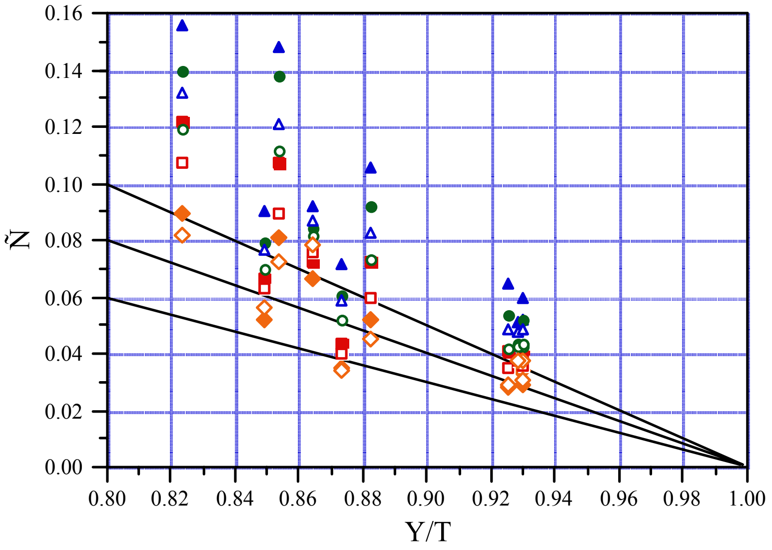
In order to clarify and not to confuse the user, the parameter N (that could be understood as the strain hardening exponent), has been renamed as Ñ. Any other variable follows the nomenclature in Report/SINTAP/UC/07.

Material	*Ñ (Y-U) Yield point not fixed*	*Ñ (Y-F) Yield point not fixed*	*Ñ (Y-(Y+F)/2) Yield point not fixed*	*Ñ (Y-U) Yield point fixed*	*Ñ (Y-F) Yield point fixed*	*Ñ (Y-(Y+F)/2) Yield point fixed*
4Y14A2 S275 JR	0.2910	0.2912	0.2065	0.2664	0.2492	0.1844
4Y17A2 S355 J2	0.2595	0.2713	0.2084	0.2448	0.2344	0.1854
Y6T8D 355 EMZ	0.2545	0.2437	0.1875	0.2330	0.2135	0.1701
Y6T26H 450 EMZ	0.1459	0.1109	0.0786	0.1212	0.0956	0.0709
4Y18A2 450 EMZ	0.1389	0.0963	0.0714	0.1104	0.0795	0.0637
Microalloyed E500	0.0728	0.0480	0.0341	0.0547	0.0414	0.0345
Y6A22D2C StE690	0.0921	0.0587	0.0400	0.0689	0.0470	0.0346
Y6A4A4D StE690	0.0645	0.0334	0.0220	0.0487	0.0361	0.0247
Microalloyed E690 (1)	0.0322	0.0196	0.0152	0.0260	0.0172	0.0142
Microalloyed E690 (2)	0.0479	0.0258	0.0154	0.0295	0.0191	0.0138
Microalloyed E690 (3)	0.0319	0.0196	0.0152	0.0257	0.0172	0.0143
Microalloyed E690 (4)	0.0379	0.0199	0.0122	0.0232	0.0143	0.0102
Normalised 4135A (1)	0.0684	0.0455	0.0364	0.0573	0.0438	0.0396
Normalised 4135A (2)	0.1465	0.1665	0.1933	0.1617	0.1798	0.2024
Quenched 4135B	0.2324	0.2779	0.2847	0.2509	0.2788	0.2813
Austenitic steel	0.2526	0.1907	0.1449	0.2025	0.1609	0.1336
Aged stainless steel	0.2291	0.1888	0.1827	0.2123	0.1875	0.1850
Stainless weld steel	0.1795	0.1101	0.0729	0.1200	0.0860	0.0656
Aluminium	0.2764	0.3318	0.3052	0.2920	0.3120	0.2865

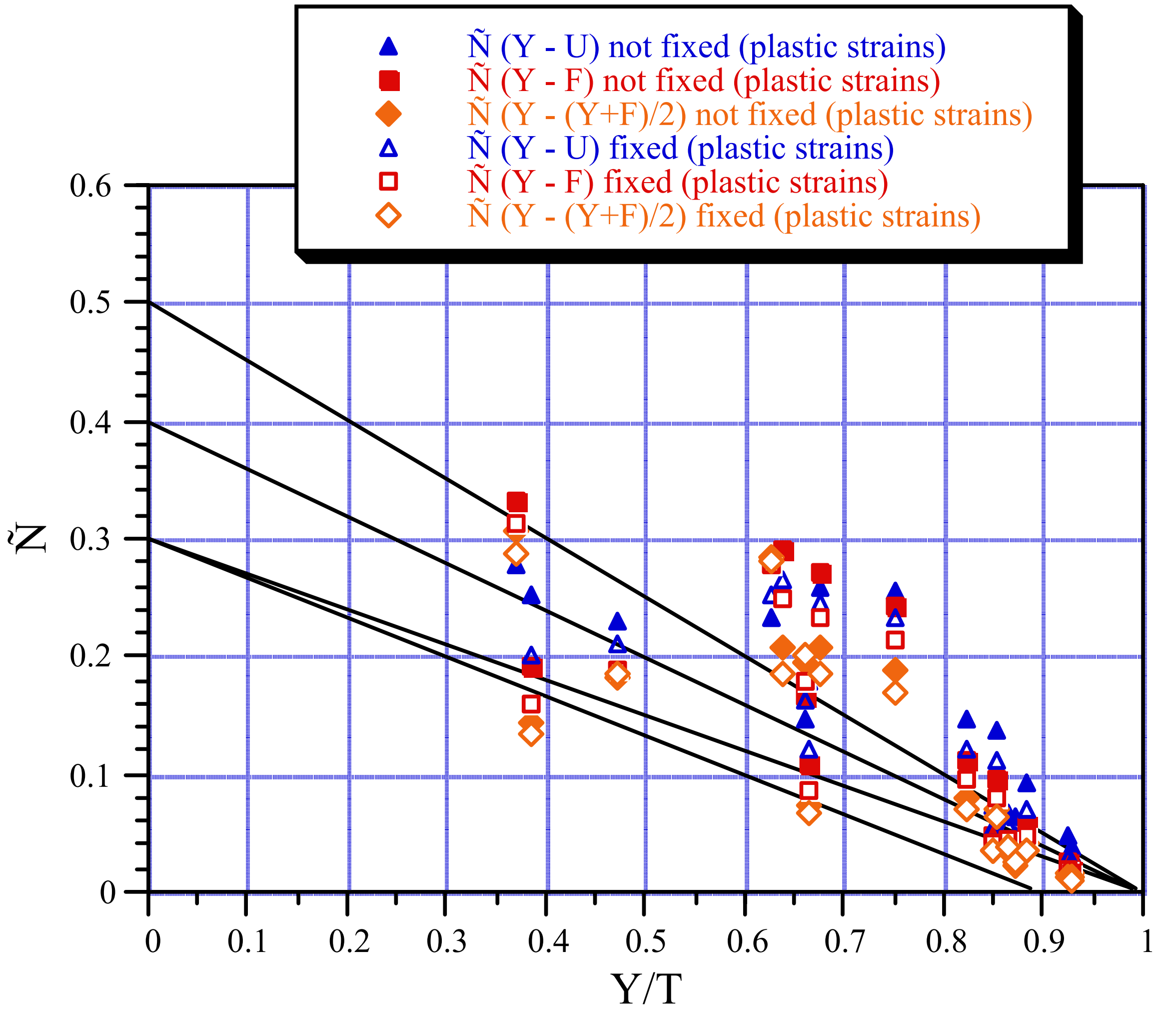
These results are also presented in following Figures where they can be compared to those resulting from total strains. It can be seen that the range of results is now smaller than in Report/SINTAP/UC/07 and that the numbers are always lower than the corresponding ones for total strain.



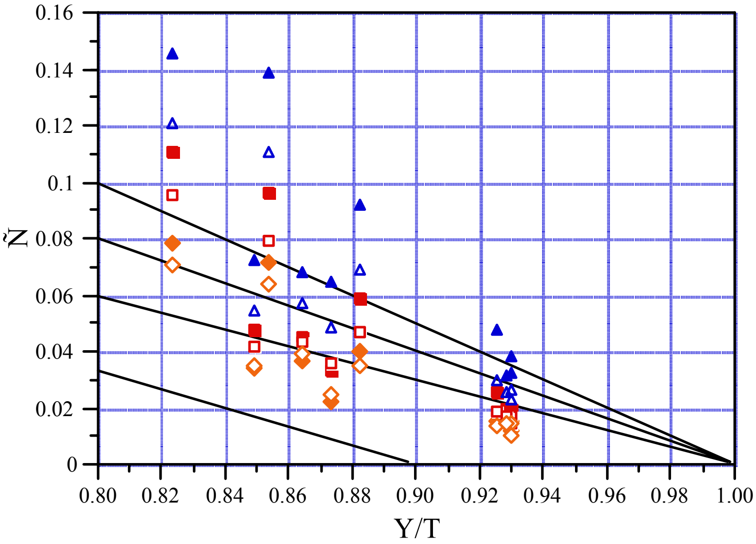
All different definitions of Ñ versus Yield/Tensile Ratio (total strain data)



Detail of the previous figure



All different definitions of Ñ versus Yield/Tensile Ratio (plastic strain data)



Detail of the previous figure

In the previous Figures, different lines have also been plotted. These are meant to provide safety estimations of Ñ. As can be seen, a single line can be proposed:

$$\tilde{N} = 0.3\left(1 - \frac{YS}{UTS}\right)$$

This line gives quite good results except for high yield/tensile ratios (over 0.85 aproximately).

Another option could be to propose a function that does not consider the effects of hardening when the yield/tensile ratio is very high (greater than 0.90). Hence resulting:

$$\tilde{N} = 0.3 - \frac{1}{3}\frac{YS}{UTS} \quad (\text{for } \frac{YS}{UTS} < 0.9) \ \text{ and } \ \tilde{N} = 0 \quad \text{for } (\frac{YS}{UTS} \ \square\ 0.9)$$

This option would be conservative for all yield/tensile ratio values.