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Fracture and fatigue properties of metallic alloys S275 J2 and Al7075 T6 at low temperatures

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Abstract Knowledge of the fracture and fatigue behaviour of metallic alloys at extreme environmental temperature conditions is required to assess the safety of structural components operating in particular fields: aerospatial, off-shore structures, power plants superconductors, polar Antarctic facilities, etc. Among the structural metallic alloys for civil, mechanical engineering and plant applications, steel S275 J2 is widely used, whereas aluminium alloys such as Al7075 T6 are significant especially for aerospatial and polar Antarctic applications. In this paper, the main experimental mechanical characteristics of such metallic materials at room temperature as well as at low temperatures are examined. Three temperatures are considered: 293 K (+20 °C, room temperature RT), 243 K (−30 °C) and 193 K (−80 °C). The corresponding values of fracture toughness and endurance limit available in the literature are reported herein. Further, experimental tests have been performed to determine the unavailable mechanical properties. Then, the values of such fracture and fatigue parameters at various temperatures are critically discussed.

Nomenclature

a	Mean value of crack length during the test
A	Cross-sectional area of the specimen
Al 7075 T6	High-strength aluminium alloy
b,c	Material's constants in Peterson and Neuber relations for notch sensitivity, respectively
CG	Crack growth
°C	Temperature (Celsius)
D	Specimen diameter
E	Young modulus of the material
$F_{\max}$	Maximum value of the applied load
K	Absolute temperature (Kelvin)
K_{IC}, $K_{\mathrm{IC}}(T)$	Fracture toughness at room temperature and at temperature T, respectively
$K_{I,\ \max}$	Stress-intensity factor at the maximum value of the applied load
K_{t}, K_{f}	Stress concentration factor and fatigue strength reduction factor, respectively
N	Number of loading cycles
NDT	Nil ductility transition
P_Q, $P_{\max}$	Applied loads defined according to ASTM B645-02
$q = (K_{\mathrm{f}} - 1)/(K_{\mathrm{t}} - 1)$	Notch sensitivity factor of the material
r	Notch root radius
R	Loading ratio
$R_{p0.2}$	0.2% deformation difference with respect to proportionality stress level
RT	Room temperature
S275 J2	Structural carbon steel
T_{DBT}	Temperature at which the ductile-brittle transition occurs
T_{NDT}	Temperature above which a metal exhibits ductile behaviour
W	Specimen width
$\alpha[°\mathrm{C}^{-1}]$	Thermal expansion coefficient of the material
σ_{f}	Endurance limit

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σ_{max}, σ_m	Maximum and mean value of the applied stress during a cycle
σ_y, σ_u	Yield stress and ultimate stress of the material
v	Poisson ratio of the material

Introduction

The evaluation of fracture toughness and fatigue limit under severe environmental conditions is very important in engineering applications (aero-spatial applications, off-shore structures, power plants, electronic devices, superconductor applications and so on) in order to quantify the structural safety according to the so-called *damage tolerant design*. In particular, the assessment of the structural safety at low temperatures should be done with extreme care since fracture and fatigue characteristics can be heavily affected by such temperatures. Fatigue behaviour should be accurately examined especially in the near-threshold region [1–3]. Several studies [4–6] have shown that metals can be roughly divided into two groups: materials with a ductile-brittle transition (DBT) and those without such a transition at low temperature. When $T > T_{DBT}$ (where T_{DBT} is the temperature at which the above-mentioned transition occurs), the crack growth (CG) mechanism consists in forming ductile striations, and the CG rate decreases by decreasing T. When T is equal to about T_{DBT}, the CG mechanism becomes micro-cleavage and the fracture toughness K_{IC} sharply decreases. If the temperature is further reduced, the CG rate tends to increase.

Among the wide family of metallic materials, in structural applications steel S275 J2 and aluminium alloy Al7075 T6 are quite relevant. In this paper, the main mechanical properties of such materials at room temperature as well as at low temperatures are examined. Three operating temperatures are considered: 293 K (+20 °C, room temperature RT), 243 K (−30 °C) and 193 K (−80 °C). Some characteristics available in the literature for the two above materials are reported hereafter. Further, experimental tests have been performed to determine fracture toughness and endurance limit at low-temperature conditions.

Structural carbon steel S275 J2

Most steels used in Europe are specified to comply with the European standard EN 10025 [7]. On the other hand, other codes use different designations for a given material or for materials very similar to each other as far as the chemical composition and mechanical behaviour are concerned.

As well known, typical grades are described as “S275 J2” or “S355 K2W”, where the symbol “S” denotes structural rather than engineering steel; the following number such as “275” (or “355”) denotes the yield strength in Newton per square millimetre or the equivalent MegaPascal (MPa); “J2” (or “K2”) denotes the material toughness related to the Charpy impact test value; the symbol “W” denotes weathering steel. Further letters can be used to designate normalized steel (“N” or “NL”), quenched and tempered steel (“Q” or “QL”), thermo-mechanically rolled steel (‘M” or “ML”) and so on.

The normal yield strength grades available are usually equal to 195, 235, 275, 355, 420, 460 MPa, although some grades are more commonly used than others (e.g. in the UK, almost all structural steels present grades S275 and S355). Higher grades are available in quenched and tempered materials (500, 550, 620, 690, 890, 960 MPa), although grades >690 MPa are not often employed.

The steel examined in this section is the S275 J2 according to EN 10025-2, which indicates a structural steel, as stated above, characterized by a minimum yield stress equal to 275 MPa, whereas the J2 symbol assures a minimum toughness (related to Charpy impact test values) equal to 27 J at 253 K (−20 °C). The chemical composition of S275 J2 is reported in Table 1 where only the main constituents are considered. The most important physico-mechanical properties of this alloy are: Young modulus $E = 206{,}000$ MPa, yield stress $\sigma_y \geq 275$ MPa, ultimate stress $\sigma_u = 420$–450 MPa, Poisson’s ratio $v \cong 0.29$, thermal expansion coefficient $\alpha = 1.2 \cdot 10^{-5}$ °C^{-1}, fracture toughness at room temperature $K_{IC}(\mathrm{RT}) \cong 140$ MPa m$^{1/2}$. Finally, it can be remarked that this alloy shows a transition temperature.

Temperature dependence of yield stress σ_y and fracture toughness K_{IC}

For the structural steel being examined, some data about the temperature dependence of the yield stress are deduced by considering an analogous material (steel with approximately a 0.2% content of Carbon) as reported in Refs. [8, 9]. In particular, an increase of about 7 and 30% with respect to the yield stress at room temperature can be observed for

Table 1 Physico-chemical and mechanical parameters (main elements) for Steel S275 J2

Element$_I$	Symbol	η_I (%max)	ρ_I (kg/m^3)	E_I (GPa)	v_I	α_I (K^{-1})
Iron	Fe	98.10	7,870	200	0.29	1.20×10^{-5}
Manganese	Mn	1.50	7,440	159	0.35	2.28×10^{-5}

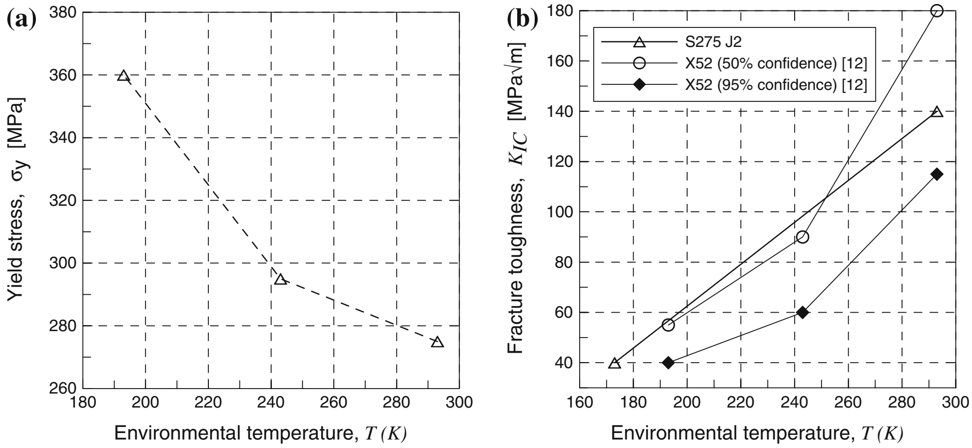


Fig. 1 Temperature dependence of the yield stress (**a**) and of the fracture toughness K_{IC} (**b**) for steel S275 J2 or similar materials [10–12]

temperature equal to 243 (−30) and 193 K (−80 °C), respectively. As far as the tensile ultimate strength is concerned, an increase of about 5 and 19% of such a mechanical property with respect to the corresponding value at room temperature can be observed for temperature equal to 243 (−30) and 193 K (−80 °C), respectively. For steel S275 J2, an analogous variation can be assumed (Fig. 1a).

Some data related to the fracture toughness at 193 K (−80 °C) are reported in Refs. [10, 12] for steels similar to S275 J2, and some experimental results are summarised in Ref. [11] for pipelines made of steel X52. In more detail, the fracture toughness of steel X52 at 293 K (+20 °C, RT), 243 K (−30 °C) and 193 K (−80 °C) is equal to about 180, 90 and 55 MPa $m^{1/2}$, respectively, by deriving mean values from experiments [11]. Further, by considering the values corresponding to 95% of confidence [11], K_{IC} is equal to 115, 60 and 40 MPa $m^{1/2}$ in correspondence to the three temperatures above, respectively. It is reported in the literature that $K_{IC}(T = 193\ \mathrm{K} = -80\ °\mathrm{C}) \cong 35$ to 40 MPa $m^{1/2}$ is the fracture toughness value for steel X52 and steel S275 J2 at such a low temperature which is under T_{NDT} (temperature of nil ductility transition, that is, temperature above which the examined metal exhibits ductile behaviour). A research survey on fracture mechanics parameters is reported in Ref. [13].

Note that for steel S275 J2, which shows low yield stress and relative high fracture toughness at room temperature (often greater than about 200 MPa $m^{1/2}$), structural components in real design are usually sized in order to get low stress values under service loading. The relative high fracture toughness normally implies the capability to carry long cracks without failure, that is, failure of such a material more often occurs for yielding than for fracture. Therefore, the interest in fracture toughness for such a material is not great. Furthermore, fracture toughness evaluation tests are difficult to be performed since a very high value of specimen thickness is required by standard tests to get the plane strain condition (as a matter of fact, the minimum thickness for plane strain conditions is proportional to $(K_{IC}/\sigma_y)^2$ [14]) and, therefore, very powerful testing machines are usually needed. Values of K_{IC} against temperature for carbon steel S275 J2 are displayed in Fig. 1b.

Fatigue limit at low temperatures

As reported in Ref. [15] for steel SS400 (definition, according to Japanese Standard JIS, for a structural steel similar to S275 J2), fatigue limit is not influenced by the loading frequency. Furthermore, due to a high ductility at room temperature, the material shows a low notch sensitivity q, defined by the expression $q = (K_f - 1)/(K_t - 1)$, where K_t, K_f are the stress concentration factor and the fatigue strength reduction factor, respectively. Such a parameter shows a dependence on the material and on the notch geometry: as suggested by Peterson [16] it can be evaluated as $q = 1/(1 + b/r)$ or, as suggested by Neuber [17], as $q = 1/\left(1 + \sqrt{c/r}\right)$ where b, c are material's constants and r is the notch root radius.

For the present material, the notch sensitivity q is equal to about 0.3–0.4 at room temperature for sufficiently high values of the notch radius [16, 17] due to the high material's ductility. In other words, at room temperature, the fatigue strength reduction factor K_f is always lower than the stress concentration factor:

$$K_f = 1 + q(K_t - 1) = 0.7 + (0.3{-}0.4) \cdot K_t \le K_t, \quad \forall K_t \ge 1.0{-}1.2.$$

At low temperatures, the strength usually increases, while ductility decreases: therefore, due to the limited stress redistribution capabilities for the reduced ductility, the notch sensitivity q increases under such temperature conditions. Consequently, $K_f = 1 + q(K_t - 1)$ increases

Table 2 Fatigue limit at room temperature for SS400 steel (IJS nomenclature) [15]

Loading	Frequency (Hz)	R	S.C.F. (K_t)	Fatigue limit σ_α (MPa) at 10^7 cycles
Axial	40.0	−1.0	1.0	152
Axial	57.5	−1.0	1.0	177
Axial	33.3	−1.0	1.04	157
Axial	57.5	−1.0	1.94	131
Axial	40.0	−1.0	2.05	115
Rotating bending	50.0	−1.0	1.0	260
Rotating bending	60.0	−1.0	1.0	218
Rotating bending	60.0	−1.0	1.0	232

and the endurance limit decreases. Data obtained from Ref. [15] are shown in Table 2.

Experimental evaluation of endurance limit at low temperatures

The evaluation of endurance limit at $N = 10^6$ cycles is very useful for fatigue assessment of structural components employed in practical applications. In this paper, such an evaluation is carried out through the so-called "pearl-string" method by testing several specimens according to ASTM E466 [18]. Tests have been performed under loading control condition, by means of a resonance system Zwick-Roell with maximum dynamic load capability equal to ±100 KN (Fig. 2a). The specimens have been subjected to a reversed cyclic axial loading (loading ratio $R = -1.0$).

Low temperatures have been obtained by using a cylindrical test chamber arranged around the specimen, and liquid nitrogen has been made to flow in the hollow wall of the cylinder, by controlling its flux through a thermocouple valve located near the specimen.

Specimen details and testing conditions are specified in Table 3, where D and A are the specimen diameter and cross-sectional area, respectively, related to the central cross section of the hourglass-shaped specimen (Fig. 2b), $\sigma_{\max}$ and σ_m are the maximum and mean applied stress, respectively, and N is the total number of loading cycles to failure. A total of six specimens identified by the symbols # S1,..., # S6 (see Table 3) have been tested.

Stress amplitude against the total number of loading cycles is displayed in Fig. 3a. Further, by using literature results from Ref. [15] and present experimental results, the temperature dependence of the endurance limit for $N = 10^6$ cycles is graphically plotted in Fig. 3b. In Ref. [15], the increase in endurance limit σ_f at $N = 10^6$ cycles with respect to $N = 10^7$ cycles (very high-cycle fatigue regime) is estimated to be equal to about 12%, that is to say, σ_f is equal to 210 and 190 MPa, respectively. From this observation, endurance limit at $N = 10^7$ cycles can be roughly estimated starting from fatigue data related to one million cycles.

The experimental endurance limit σ_f (250 MPa) obtained in this research work for $N = 10^6$ cycles is about 20% greater than the value of σ_f at $N = 10^6$ cycles reported in Ref. [15]. As well known, fatigue limit of carbon steel is approximately proportional to its tensile strength and, therefore, the above 20% increase in σ_f can be

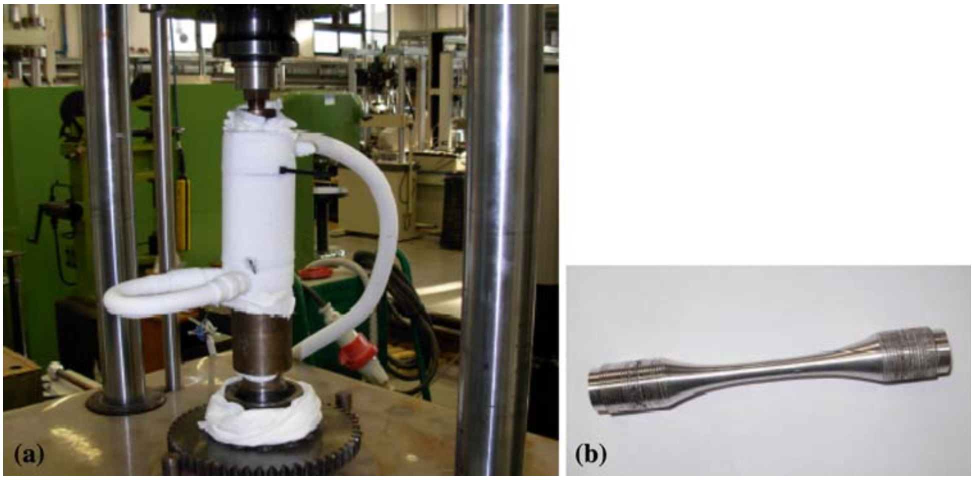


Fig. 2 Testing machine (**a**) and hourglass-shaped specimen (**b**) for fatigue limit evaluation at low temperatures

Table 3 Specimens' and testing details adopted in the present study for fatigue life evaluation at 243 K (−30 °C) for steel S275 J2

Specimen			Tests details				Fatigue life
Specimen id.	D (mm)	A (mm^2)	$\sigma_{\max}$ (MPa)	R	σ_m (MPa)	Freqency (Hz)	N, tot. no. of cycles or no. of cycles to failure
# S1	6.00	28.3	250.0	−1.0	0.0	110	1000, 000
# S2	5.99	28.2	250.0	−1.0	0.0	110	1000, 000
# S3	6.02	28.5	260.0	−1.0	0.0	108	625,000
# S4	6.02	28.5	260.0	−1.0	0.0	111	1000,000
# S5	5.97	27.9	265.0	−1.0	0.0	110	1000,000
# S6	5.96	27.9	270.0	−1.0	0.0	111	1000,000

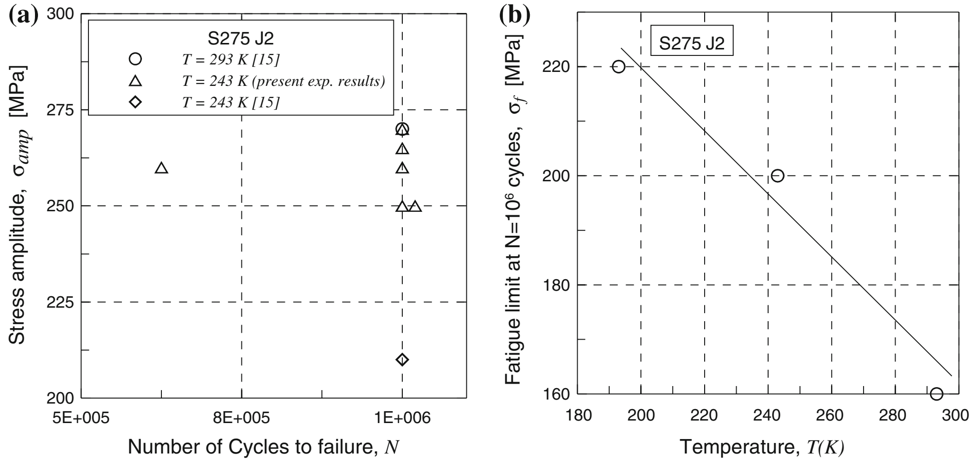


Fig. 3 Stress amplitude versus no. of cycles (**a**) and temperature dependence of the fatigue limit (**b**) for steel S275 J2

explained by considering that the tensile strength of the material here tested is equal to 559 MPa (yield stress equal to 406 MPa), that is, such a strength is about 22–33% greater than that of the common carbon steel S275 examined in Ref. [15].

High-strength aluminium alloy Al7075 T6

Al7075 T6 is a lightweight, high-strength aluminium alloy widely used in aircraft and navy applications related to very highly stressed structural components. It is composed mainly by aluminium and secondary elements such as zinc (5.5%), manganese (2%) and copper (1.5%). The "T6" symbol defines the kind of heat treatment followed by an artificially ageing at 393 K (120 °C). This material is commonly used in particular applications (aeronautical structures, power plants, polar Antarctic facilities, etc.) at low temperatures. Therefore, in order to correctly assess the structural safety at such environmental conditions, the relevant parameters—especially those related to fracture and fatigue behaviour—must be evaluated at low temperature conditions. The main physico-mechanical characteristics of Al7075 T6 are: Young modulus $E \cong 70,000$ MPa, yield stress $\sigma_y \cong 505$ MPa, ultimate stress $\sigma_u \cong 570$ MPa, Poisson's ratio $\nu \cong 0.3$, thermal expansion coefficient $\alpha \cong 2.3 \cdot 10^{-5}\ °\mathrm{C}^{-1}$, fracture toughness at room temperature $K_{IC}(\mathrm{RT}) \cong 36\,\mathrm{MPa\,m}^{1/2}$. This alloy does not show any evident transition temperature, at least in the temperature range of interest for structural applications [19, 20]. The chemical composition of Al7075 T6 is reported in Table 4 where only the main constituents are considered.

The yield stress of aluminium alloys changes by decreasing the temperature by a minimum amount (1–3%) from the RT to 243 K (−30 °C), while this variation is about 4–7% up to 193 K (−80 °C) [21]. As reported in the literature, this trend is common to all the similar aluminium

Table 4 Physico-chemical and mechanical parameters (main elements) for Al7075

Element$_I$	Symbol	η_I (%)	ρ_I (kg/m^3)	E_I (GPa)	ν_I	α_I (K^{-1})
Aluminium	Al	90.50	2,700	68.00	0.33	2.40×10^{-5}
Zinc	Zn	5.50	7,100	96.50	0.30	3.12×10^{-5}
Magnesium	Mg	2.00	1,740	44.00	0.35	2.61×10^{-5}
Copper	Cu	1.50	8,960	110.00	0.34	1.64×10^{-5}

Table 5 Specimens' and testing details adopted in the present study for K_{IC} evaluation at low temperatures for aluminium alloy Al 7075 T6

Specimen			Pre-crack process				Tests details			
Specimen id.	B (mm)	W (mm)	$F_{\max}$ (N)	R	No. cycles	$K_{I,\max}$ (MPa$\sqrt{m}$)	P_Q (kN)	$P_{\max}$ (kN)	α (mm)	$R_{p0.2}$ (MPa)
# A1	29.59	59.01	12,000	0.1	63,000	14.86	19.42	19.42	32.21	505
# A2	29.60	59.15	12,000	0.1	52,000	12.52	21.62	21.62	29.30	505
# A3	29.59	59.09	12,000	0.1	50,000	12.65	21.92	21.92	29.42	505
# A4	29.59	59.07	12,000	0.1	53,000	12.65	20.05	20.05	29.41	505
# A5	29.62	59.07	12,000	0.1	53,000	12.66	19.92	19.92	29.44	505
# A6	29.60	59.18	12,000	0.1	52,000	12.69	19.37	19.37	29.55	505

alloys and, therefore, the same trend can be considered for Al7075 T6.

K_{IC} at different temperatures

In Refs. [18, 21], some values of fracture toughness are reported. Some relevant values are: $K_{IC}(353K = +80\,^{\circ}C) = 38$, $K_{IC}(293\ K = +20\ ^{\circ}C) = 36$ and $K_{IC}(253\,K = -20\ ^{\circ}C) = 27$ MPa $m^{1/2}$ (note that K_{IC} is equal to about 27 MPa $m^{1/2}$ up to 223 K, −50 °C). If the temperature is further reduced up to 193 K (−80 °C), the fracture toughness decreases continuously but slightly: a conservative value is $K_{IC}(T = 193\ K = -80\ ^{\circ}C) = 25$ MPa $m^{1/2}$.

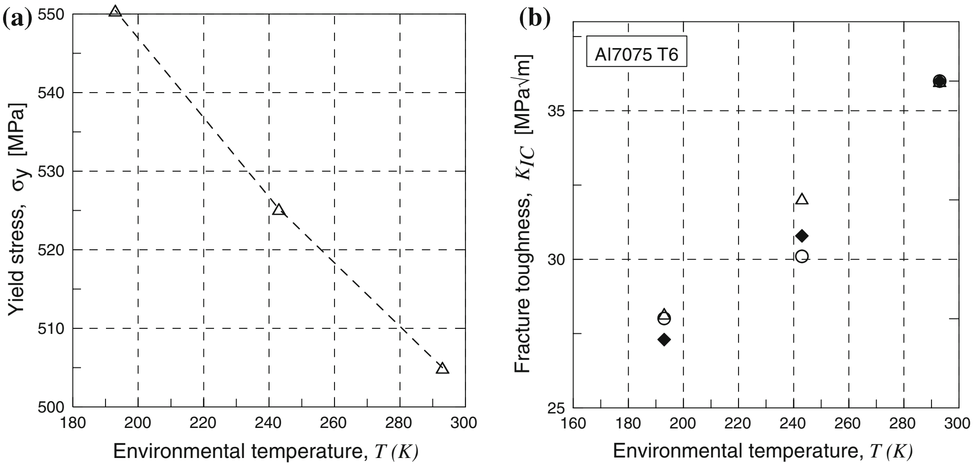
Since the value of fracture toughness at temperature 243 K (−30 °C) is not available for such a material, some tests have been conducted by employing Disc-shaped Compact test specimen (DC(T) specimens, Tension test). Specimen sizes and testing procedure have been adopted in accordance with ASTM E399 [22]. The pre-existing crack required by the test has been produced in the specimens at ambient temperature by a fatigue machine under cycling loading control, with $R = 0.1$ and load frequency equal to 12 Hz.

Specimen details and testing conditions are specified in Table 5, where B and W are the specimen thickness and width, respectively; $F_{\max}$, N, $K_{I,\max}$ are the maximum applied load, the number of loading cycles, the maximum stress-intensity factor during the pre-cracking process, respectively; P_Q, $P_{\max}$, a, $R_{p0.2}$ are the conventional load (defined according to ASTM B645-02 [14]), the maximum value of the applied load, the mean value of crack length during the test, the 0.2% deformation difference with respect to proportionality stress level, respectively. Six specimens identified by the symbols # A1,..., # A6 (see Table 5) have been tested. The test temperature (243 K, −30 °C) has been obtained from injection of atomised nitrogen in the hollow cylindrical test chamber, by controlling its flux through a thermo-couple valve.

Table 6 Fracture toughness K_{IC} at two low temperatures (243 K): values obtained in the present study for aluminium alloy Al 7075 T6

Specimen id.	Test temperature, T (K)	K_{IC} (MPa$\sqrt{m}$)
# A1	243	32.05
# A2	243	30.10
# A3	243	30.79
# A4	193	28.17
# A5	193	28.01
# A6	193	27.30

Fig. 4 Temperature dependence of the yield stress (**a**) [19] and of the fracture toughness K_{IC} for Al7075 T6 (**b**) where symbols indicate different experimental tests values obtained in this study



The temperature dependence of fracture toughness is plotted in Fig. 4b, and the obtained results are displayed in Table 6 for six tested specimens.

Experimental evaluation of endurance limit at low temperatures

Similarly to austenitic steels, a well-defined fatigue limit does not exist for aluminium alloys. For this reason, a fatigue limit value at a very high number of loading cycles (usually $N = 10^7$ cycles) is usually provided. Nevertheless, as discussed for steel S275 J2, the evaluation of endurance limit at $N = 10^6$ cycles is very useful for fatigue assessment of structural components employed in practical situations. Some data for fatigue limit at $N = 10^7$ cycles are reported in Ref. [14]: such a parameter evaluated at room temperature by performing a push–pull test with $R = -1$ is equal to about 150 MPa for unnotched specimen, while it is equal to about 70 MPa for notched specimen characterised by a stress concentration factor $K_t = 3.4$. In Ref. [23], the increase in endurance limit σ_f at 77 K (−196 °C) with respect to the corresponding room temperature value is reported to be equal to about +40%, whereas the σ_f variation at 195 K (−78 °C) is about +10%. Such a behaviour is quantitatively similar to that of the tensile strength for the above temperatures: since fatigue limit is usually approximately proportional to the tensile strength, the above results are in good agreement with the expected values of σ_f.

As previously discussed for steel S275 J2, the evaluation of endurance limit has been performed by the so-called "step down test" or Wöhler test ("pearl-string" method) [24]. A total of seven hourglass-shaped specimens (Fig. 2b) identified by the symbols # A7,..., # A14 (see Table 7) have been tested. The testing procedure is the same as that described in section "Experimental evaluation of endurance limit at low temperatures". Specimen details and testing conditions are listed in Table 7.

The maximum applied cyclic stress against the total number of cycles is plotted in Fig. 5a, and the temperature dependence of endurance limit σ_f for $N = 10^6$ cycles is

Table 7 Specimens' and testing details adopted in the present study for fatigue life evaluation at 243 K (−30 °C) for aluminium alloy Al 7075 T6

Specimen			Tests details				Fatigue life
Specimen id.	D (mm)	A (mm^2)	σ_{max} (MPa)	R	σ_{max} (MPa)	Frequency (Hz)	N, tot. no. of cycles or no. of cycles to failure
# A7	5.95	27.8	150.0	−1.0	0.0	84	1000,000
# A8	5.96	27.9	200.0	−1.0	0.0	83	417,000
# A9	5.95	27.8	180.0	−1.0	0.0	83	1000,000
# A10	5.95	27.8	190.0	−1.0	0.0	80	1000,000
# A11	5.97	28.0	195.0	−1.0	0.0	81	950,000
# A12	5.95	27.8	205.0	−1.0	0.0	16	410,000
# A13	5.98	28.0	220.0	−1.0	0.0	16	20,166
# A14	5.98	28.1	185.0	−1.0	0.0	16	1000,000

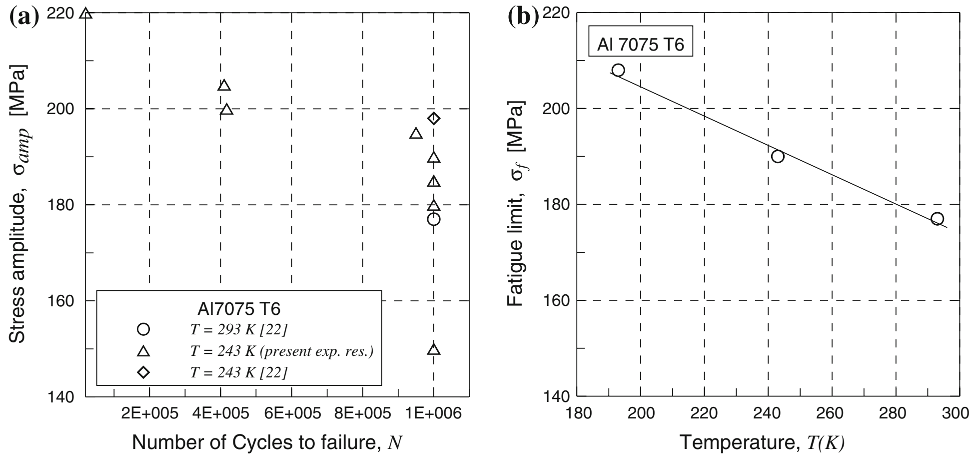


Fig. 5 Values obtained experimentally in this study for the stress amplitude versus no. of cycles (**a**) and temperature dependence of the fatigue limit (**b**) for aluminium alloy Al7075 T6 obtained in the present study. Some values from [22] are also reported

displayed in Fig. 5b. It can be observed that endurance limit can be considered to be equal to 190 and 210 MPa at 243 (−30) and 193 K (−80 °C), respectively. Note that the increase in endurance limit at $N = 10^6$ cycles with respect to $N = 10^7$ cycles is estimated to be equal to about 18% in Ref. [15], that is to say, by using the present experimental results, the value of σ_f at $N = 10^7$ cycles would be equal to 150 and 180 MPa, respectively.

Discussion

From the literature data or present experimental values reported above, some remarks can be made regarding the mechanical behaviour of steel S275 J2 and aluminium alloy Al7075 T6 at low temperatures.

As far as steel S275 J2 is concerned, by decreasing the temperature from 293 (+20 °C, room temperature RT) up to 193 K (−80 °C), the main changes of the mechanical behaviour are as follows. The yield stress increases about 7.5% at $T = 243$ K (−30 °C), whereas it increases about 31% at $T = 193$ K (−80 °C). In the same range of temperatures (293–193 K), the fracture toughness decreases of about 55–65% since the transition temperature for brittle behaviour is higher than such temperature values.

Endurance limit for $N = 10^6$ cycles increases of about 36% if the temperature decreases from 293 (+20 °C, room temperature RT) to $T = 193$ K (−80 °C), i.e. the temperature decrease influences fatigue behaviour less than the fracture toughness. As a matter of fact, fatigue limit is usually proportional to the ultimate stress which tends to increase by decreasing the temperature. On the other hand, for low temperatures, strength and notch sensitivity tend to increase, and fatigue limit decreases.

The behaviour of aluminium alloy Al7075 T6 at low temperature is significantly different from that of steel S275 J2. By decreasing the temperature from 293 (+20 °C, room temperature RT) up to 193 K (−80 °C), the main changes of the mechanical characteristics are the following ones. The yield stress increases of about 4% at $T = 243$ K (−30 °C), whereas it increases of about 9% at $T = 193$ K (−80 °C). In the same range of temperatures (293–193 K), the fracture toughness decreases of about 20–22%.

On the other hand, the endurance limit σ_f for $N = 10^6$ cycles increases of about 12% if the temperature decreases from 293 (+20 °C, room temperature RT) to $T = 193$ K (−80 °C), i.e. fatigue behaviour is not remarkably influenced by the temperature decrease.

From the data presented in this paper, it is possible to state that the temperature dependence of the fracture and fatigue parameters is much more pronounced for structural steel S275 J2 than for Al7075 T6. Both fracture toughness and endurance limit changes for the two materials are in a ratio equal to about 2–3, i.e. the variations of fracture toughness (decrease) and endurance limit (increase) for steel S275 J2 are about two to three times greater than those for aluminium alloy Al 7075 T6.

Conclusions

Fracture and fatigue behaviour of metallic alloys at low temperatures have been examined. The need to properly evaluate such a behaviour becomes evident when safety assessment of a structural component operating in extreme environmental conditions is required. Among metallic alloys, steel S275 J2 and lightweight aluminium alloy Al7075 T6 are very often used in structural engineering fields.

In this paper, the main mechanical characteristics of such alloys at room temperature as well at low temperatures have been collected from the literature or have been experimentally determined. Three temperatures have been considered: room temperature 293 K (+20 °C, room temperature RT), 243 K (−30 °C), 193 K (−80 °C). In particular, the temperature dependence of fracture toughness and endurance limit of such materials has been analysed.

It can be concluded that the temperature dependence of the fracture and fatigue parameters is much more pronounced for steel S275 J2 than for Al7075 T6. The latter material can be used in structural engineering applications with a wide range of temperature below the standard room temperature. If well designed, also structural components made of steel S275 J2 can be employed at low temperatures.

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