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Characteristics of Non-Ferrous Metal Alloys as Determined by Low-Cycle Fatigue Test under Variable Loads

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Abstract

The paper presents the results of comparative tests of the fatigue properties conducted on two non-ferrous alloys designated as Al 6082 and Al 7075 which, due to the satisfactory functional characteristics, are widely used as engineering materials. The fatigue tests were carried out using a proprietary, modified low cycle test (MLCF). Particular attention was paid to the fatigue strength exponent *b* and fatigue ductility exponent *c*. Based on the tests carried out, the results comprised within the range defined by the literature were obtained. These results prove a satisfactory sensitivity of the method applied, its efficiency, the possibility of conducting tests in a fully economical way and above all the reliability of the obtained results of the measurements. Thus, the thesis has been justified that the modified low cycle fatigue test (MLCF) can be recommended as a tool used in the development of alloy characteristics within the range of low-cycle variable loads

Keywords: Fatigue resistance, Low-cycle fatigue test (LCF), Material constants

1. Introduction

One of the main problems concerning the properties of materials is the knowledge of their behaviour under variable and fast-changing loads, that is – knowing their fatigue strength [1]. Such studies are both time-and labour-intensive and require disposal of a large collection of samples. That is why, also for these reasons, efforts are continuously undertaken to improve the methods for the development of fatigue characteristics. Based on the experience gained from previous own research [2, 3, 4], in this study, the fatigue characteristics of selected non-ferrous alloys were evaluated using a modified version (MLCF - [2, 3, 4]) of low-cycle fatigue test (LCF) [3]. Advantages of MLCF can be formulated in a short claim that this method is objective, which is a *sine qua non* condition, and economic at the same time. The economic attractiveness is due to the fact that a small number of samples is needed in the test, which is a source of significant material savings compared to the classical method of LCF; the test time is much shorter, too. From a substantive point of view, MLCF method is particularly useful in all those cases where the test material is characterised by microstructural heterogeneities, impeding proper construction of Wöhler diagrams. Details of the advantages of using the newly developed MLCF method were disclosed in detail in [2, 3, 4].

2. Test material

Fatigue tests were carried out on samples of Al 6082 and Al 7075 alloys, whose chemical composition was comprised in a range recommended by EN 573-3 standard. The shape and dimensions of the tested alloy samples are shown in Figure 1 and Table 1.

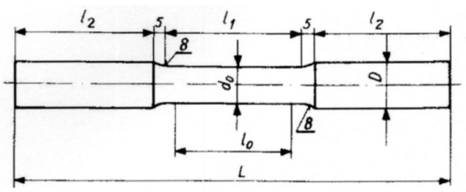

Fig. 1. The geometry of samples used in tests

Table 1.
Dimensions of the specimens used in mechanical tests.

d_0 [mm]	D [mm	l_0 [mm]	l_1 [mm]	l_2 [mm]	L [mm]	D [mm]	H [mm]
8	**10**	**40**	**45**	**30**	**125**	**12**	**16**

The selection of alloys based on the statement that both of the above mentioned alloys are widely used in practice. Alloys from the 6XXX and 7XXX series are precipitation hardened, and owing to this show good mechanical properties combined with satisfactory ductility. However, remembering the well-known fact that the higher is the strength, the lower is the toughness, a reasonable compromise must be sought to best suit the current needs. The 6xxxseries alloys are characterised by elevated mechanical properties, corrosion resistance in ordinary and marine water environments, good weldability and formability by deep drawing. Therefore alloys from this series are used for mildly loaded elements used in the marine and aerospace industries and for the production of equipment used by the food and chemical industries. The Al 6082 alloy selected for testing is used for the supporting elements of trucks, buses, trailers, ships, cranes, rail cars, bridges, and safety barriers. This alloy is used for parts of tanks, hydraulic systems, mining equipment, poles, and beams for the construction of ships and boats [5]. Alloys from the 7XXX series, also known as dural zinc alloys, are characterised by the highest strength parameters of all wrought aluminium alloys. However, they have poor resistance to the effect of elevated temperatures and corrosion, stress corrosion, in particular. Dural zinc alloys are used for parts of machines, vehicles, rolling stock and aircraft structures. The Al 7075 alloy selected for testing is used for blow moulds, moulds for plastic foam elements, parts of punching and stamping equipment, highly stressed machine parts operating in the aerospace industry, and heavily loaded components for the manufacture of sports equipment [5].

3. Mechanical testing of Al 6082 and Al 7075 alloys

Fatigue characteristics of Al 6082 and Al7075 aluminium alloys were determined from the results of tests carried out by the modified low-cycle fatigue method (MLCF). Fatigue tests were carried out on an INSTRON machine, where the machine control software was written in a LabView environment using Instron drivers [2, 3, 4].
Table 2 summarizes the results of mechanical tests carried out on non-ferrous alloys in Al 6082 grade (samples 1, 2 and 3) and Al 7075 grade (samples 4 and 5) in accordance with the MLCF methodology. Figures 2-5 show the selected diagrams $\sigma = f(\varepsilon)$ [6].

Table 2.
The results of mechanical testing of Al 6082 and Al 7075 aluminium alloys

Sample No.	R_m [MPa]	$R_{0.02}$ [MPa]	$R_{0.2}$ [MPa]	R_a [MPa]	Z_{go} [MPa]	b	c	n'	K [MPa]	$\varepsilon_{\cdot max}$ $.10^6$
1	380.0	289.5	332.6	362.5	159.2	-0.07556	-0.69330	0.033448	359.1	1812
2	334.0	255.0	282.6	324.4	140.2	-0.07538	-0.75655	0.02842	311.9	1574
3	332.5	256.8	290.5	324.0	141.3	-0.07434	-0.87382	0.03546	308.9	1572
4	659.3	453.2	608.6	642.3	243.6	-0.08650	-0.68818	0.02671	639.0	2527
5	703.7	472.4	600.0	491.9	254.7	-0.08826	-0.43852	0.02572	653.6	2652

Figures 2 to 4 show the results of fatigue tests conducted on Al 6082 and Al 7075 alloys. The results in the form of stress-strain diagrams $\sigma = f(\varepsilon)$ are displayed in Figures 2a-b and 3 for the Al 6082 alloy and in Figure 4 a-b for the Al 7075 alloy.

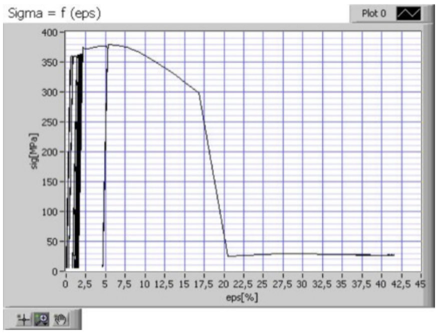

Fig. 2a. The stress-strain diagram σ = f(ε) plotted for Al 6082 alloy; sample 1

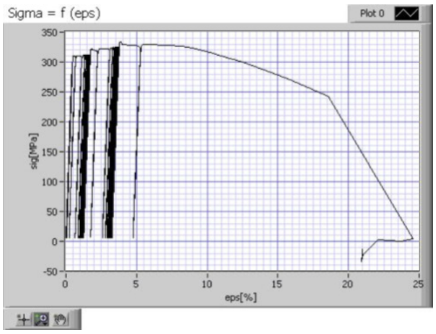

Fig. 2b. The stress-strain diagram σ = f(ε) plotted for Al 6082 alloy; sample 2

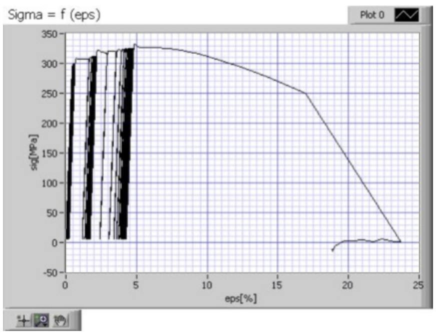

Fig. 3. The stress-strain diagram σ = f(ε) plotted for Al 6082 alloy; sample 3

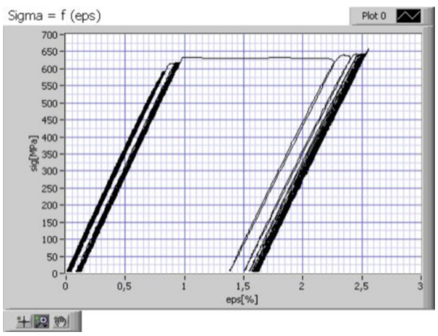

Fig. 4a. The stress-strain diagram σ = f(ε) plotted for Al 7075 alloy; sample 4

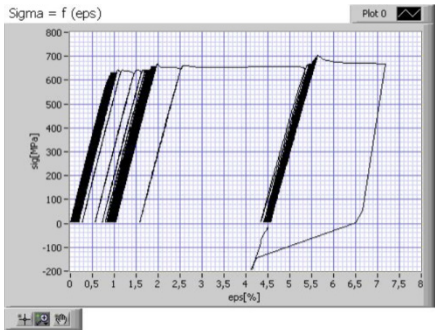

Fig. 4b. The stress-strain diagram σ = f(ε) plotted for Al 7075 alloy; sample 5

Based on the results of mechanical tests conducted by the MLCF method (Table 2) on Al 6082 and Al 7075 alloys, it can generally be stated that the expected values of the fatigue strength exponent *b* and fatigue ductility exponent *c* are comprised in the range of values reported in the literature [7], which means that both parameters should be within the following limits:

***b*: from -0,05 to -0,15; *c*: from -0,5 to -0,7**

The average value of the fatigue strength exponent of the Al 6082 alloy was b = -0.07509, and the average value of the fatigue ductility exponent was c = -0.7745, which means the value slightly above the upper range. On the other hand, for the Al 7075 alloy, the average value of the fatigue strength exponent was b = -0.08738, and of the fatigue ductility exponent c = -0.56335, and thus both values remained within the lower interval of the range. As regards the maximum admissible total plastic strain ε_{max}, for the Al 6082 alloy its average value was ε_{max} 106 = 1652, and for the Al 7075 alloy it was ε_{max} 106 = 2589.

Fractures of all Al 6082 alloy samples obtained from the fatigue test performed by MLCF and pictured by SEM technique (Figs. 5-16) are of similar quality and can be classified as ductile with visible, characteristic and numerous pits (which are marked directly on the images of fractures (Fig. 8). In the examined alloys, the presence of fatigue striations was not detected. The fractures of all Al 7075 alloy samples obtained in the fatigue test performed by MLCF are also qualitatively similar in nature (Figs. 17-24). The fractures of all samples obtained in the fatigue test performed by MLCF can be classified as mixed ductile-brittle with visible characteristic pits, cleavage planes and cracks, which are marked directly on the fracture images (Figs. 20, 23-24).

4. Summary

The proposed algorithm for fatigue tests adapted to the Instron 8802 universal testing machine [6] as well as the previously developed algorithm for MTS testing machine [1, 5] fulfilled the task adequately, because the basic *b* and *c* parameters of the low-cycle test were comprised in the range of values reported in the literature. Thus, it is reasonable to claim that the MLCF method can provide a good and reliable tool to estimate a number of mechanical properties determined during single experiment.

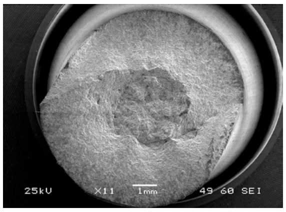

Fig. 5. Al 6082
Sample 1, x11, SEM

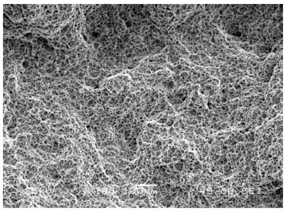

Fig. 6. Al 6082
Sample 1 x100, SEM

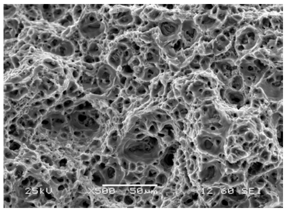

Fig. 7. Al 6082
Sample 1 x500, SEM

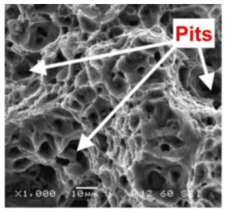

Fig. 8. Al 6082
Sample 1, x1000, SEM

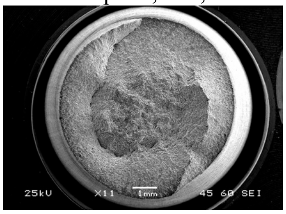

Fig. 9. Al 6082
Sample 2, x11, SEM

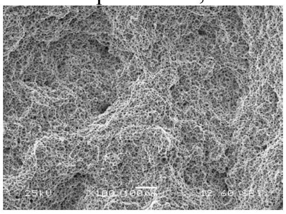

Fig. 10. Al 6082
Sample 2, x100, SEM

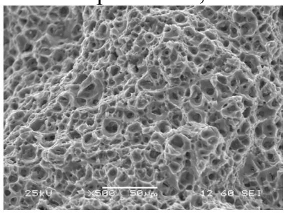

Fig. 11. Al 6082
Sample 2 x500, SEM

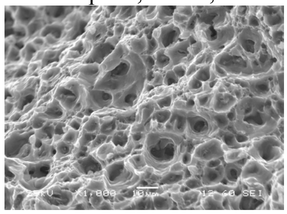

Fig. 12. Al 6082
Sample 2, x1000, SEM

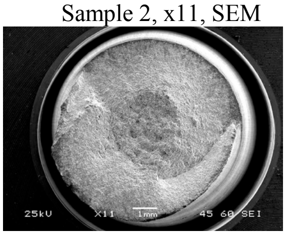

Fig. 13. Al 6082
Sample 3, x11, SEM

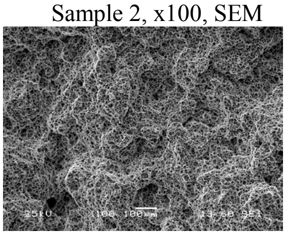

Fig. 14. Al 6082
Sample 3, x100, SEM

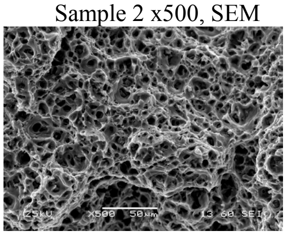

Fig. 15. Al 6082
Sample 3 x500, SEM

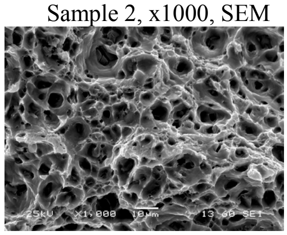

Fig. 16. Al 6082
Sample 3, x1000, SEM

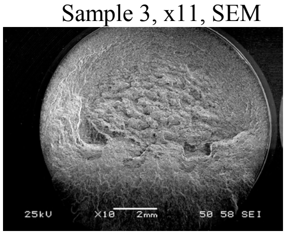

Fig. 17. Al 7075
Sample 4, x10, SEM

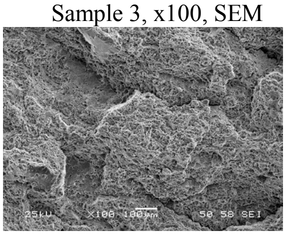

Fig. 18. Al 7075
Sample 4, x100, SEM

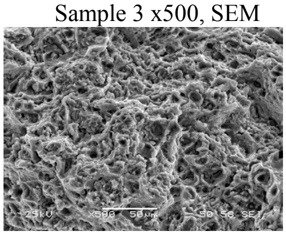

Fig.19. Al 7075
Sample 4, x500, SEM

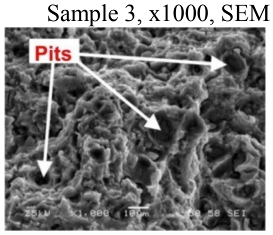

Fig. 20. Al 7075
Sample 4, x1000, SEM

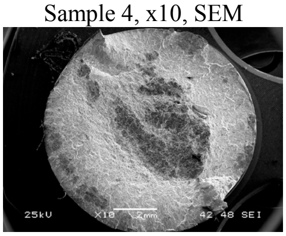

Fig. 21. Al 7075
Sample 5, x10, SEM

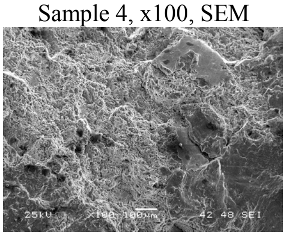

Fig. 22. Al 7075
Sample 5, x100, SEM

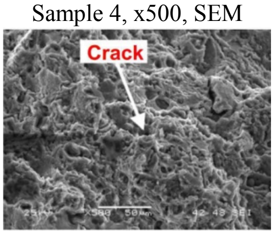

Fig. 13. Al 7075
Sample 5, x500, SEM

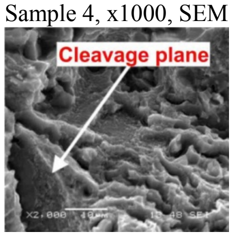

Fig. 24. Al 7075
Sample 5, x2000, SEM

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