

Structural Analysis of Carabiners Materials Used at Personal Protective Equipments

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Abstract. Thus specialized shackles are used in severe environment condition, such as: temperature variation (firefighters, mountain climbers), highly corrosive (construction, caving, sailing), etc. so it must be manufactured from materials with good corrosion resistance and refractoriness. Because the carabiners are used at height, besides the properties already exposed, they must possess properties of resilience. This paper presents a metallographic analysis using Scanning Electron Microscope and Energy Dispersive Analysis X-ray to highlight the structural characteristics in order to increase resilience and improve the wear and corrosion resistance properties.

1. Introduction

A carabiner is a special type of shackle with a spring-loaded closure used to connect components quickly and reversibly, mainly at safety systems and to attach elements to a belt or band [1].

Using range of carabiners includes: mountaineering, caving, climbing utility, construction, rescue, arboriculture [2], canoeing and yachting.

Due to their low specific weigh, almost all shackles currently used for climbing are made of aluminum alloys. [3] For situations where weight is not an important factor, such as fixed anchors, steel carabiners are used due to their high wear resistance and tensile strength.

When used for fire rescue or mountaineering courses, steel carabiners are excellent. Refractory steel keeps its integrity at temperatures above 500 °C, making it ideal for evacuation and rescue operations including high temperatures [4]. However, steel carabiners as fire safety connectors are not indicated, because steel loses its resistance properties long before it melts. The steel is hard, high tensile strength and relatively elastic, making it resistant to cracking or deformation [5]. Carbon steel carabiners will rust quickly if exposed to fresh or salt water, while stainless steel is not as wear-resistant, but has much better corrosion properties [6].

The main aluminum carabiners advantage is the low specific weight. Aluminum alloys based on Al-Cu, Zn, Mg, Cr systems are hardened by solution annealing and quench-ageing [7]. Typically, the 7075-T6 is used for the carabiners body and locking element [8].

2. Linking elements analysis

2.1. Carabiners classification

According to SR EN 12275 *Mountaineering equipment – Connectors – Safety requirements and test* [9] standard, carabiners are classified as can be seen in Table 1.



Table 1. Types of carabiners.

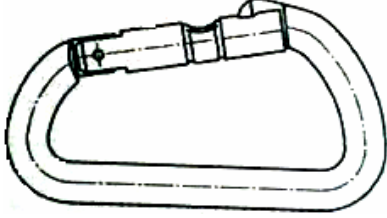
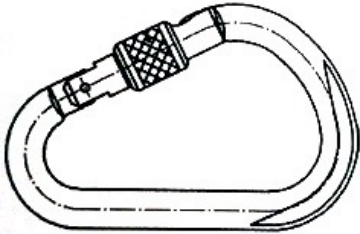
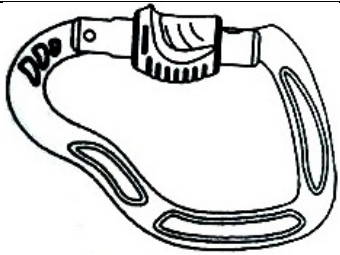
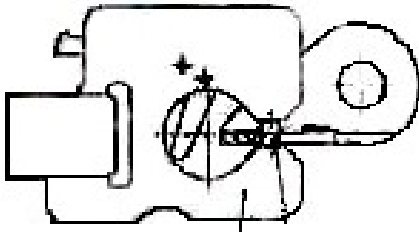
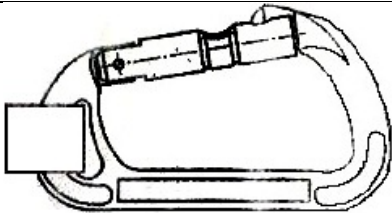
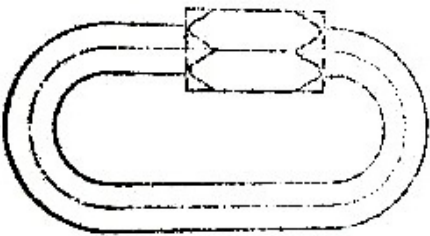
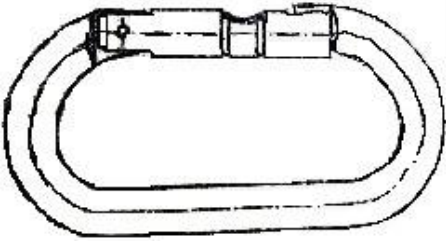
Type	Name	Scheme	Rl_1^1	Rl_2^2	Rt^3
B	Basic carabiner		20KN	7KN	7KN
H	HMS carabiner		20KN	6KN	7KN
K	Klettersteig carabiner		25 KN	8KN	7KN
A	Special piton carabiner		20KN	7KN	
T	With secured position		20KN	7KN	
Q	With threaded gate		25KN		10KN

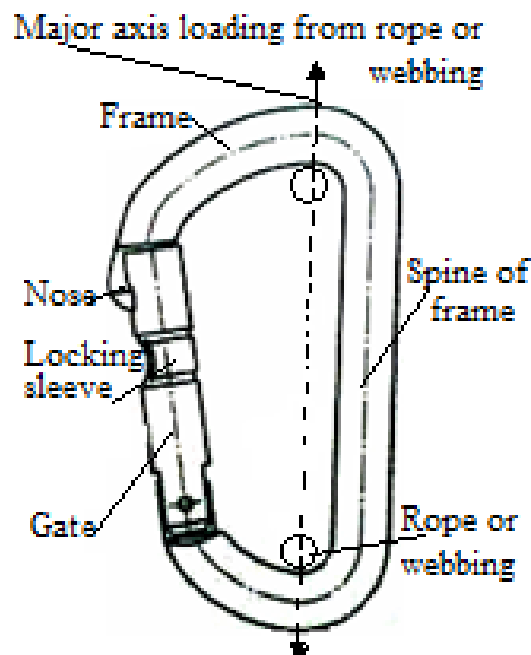
Table 1. Types of carabiners.

Type	Name	Scheme	RI_1^1	RI_2^2	Rt^3
X	Oval carabiner		18KN	5KN	7KN

¹Static resistance on longitudinal axis with gate closed²Static resistance on longitudinal axis with gate open³Static resistance on transversal axis

2.2. Standards and requests

In mountain climbing, thus are used to connect safety rope to anchors in order to stop the climber fall, if necessary. Carabiners are often sold in pairs, attached together through a nylon strap. While one is attached to the anchor, the other one is rope clamped. The requirements of a carabiner can be grouped after loading, geometry or environmental conditions [10].

**Figure 1.** Schematic presentation of a carabiner.

Minimum load requirements for climbing connectors are presented by international and European standards. For current aluminium alloys carabiners, EN and UIAA standards described the safety tests. [9, 11, 12]. Carabiners should not be thrown or dropped from heights because scratches can occur on their surfaces due to impacts and may affect their physical properties. Thus must always work correctly, the gate should automatically and completely shut off after releasing, locking may be automatically or by screwing, any geometrical modification are not allowed. Environmental characteristics are very important because humidity and temperature variation can have significant effects on material properties. Carabiners can be exposed at very high temperature ranges, from -40°

C (Everest peak) to + 80 ° C (due to friction during descent) [8]. Besides these, it is necessary to know the material chemical resistance properties.

3. Structural analysis

Due to the carabiners operating conditions, the manufacturing materials must have good corrosion and shock elasticity properties.

This paper focuses on structural analysis of x type carabiner (Figure 2) used for low loads to attaché the rope to the piton. It is made of steel, has a minimum tensile strength of 22 kN and a mass of 175 g. Due to its design, the load is always in the middle of the carabiner body.

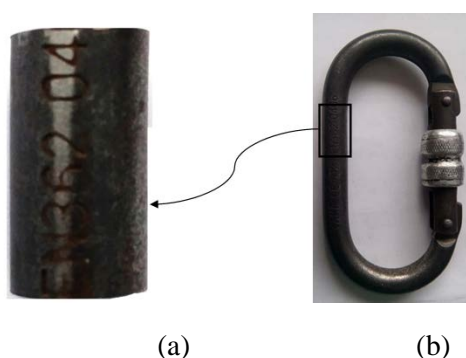


Figure 2. X type carabiner, (a) studied sample, (b) full carabiner.

The chemical composition (Table 2) of the sample has been determined by optical emission spectrometry using a Foundry Master spectrometer. According to values obtained, the steel grade is C45 (SREN 10083-2 (2006)).

Table 2. Chemical composition.

Element	Fe	C	Si	Mn	P	S	Ni	Cr
Percent	balance	0.47	0.13	0.75	0.03	0.03	0.20	0.15

Metallographic investigations have been carried out on the carabiner material by cutting multiple segments for samples. The microstructure presented in Figures 3, 4a and b consists of equiaxed pearlitic-ferrite grains with well-defined grain boundary and relatively uniform distribution of the pearlitic grains. The EDX analysis performed shows the structure uniformity also from chemical point of view (Figure 4 c).

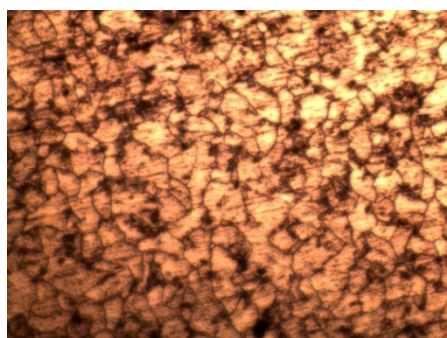


Figure 3. Optical microstructure, X50. Equiaxed pearlitic-ferrite grains.

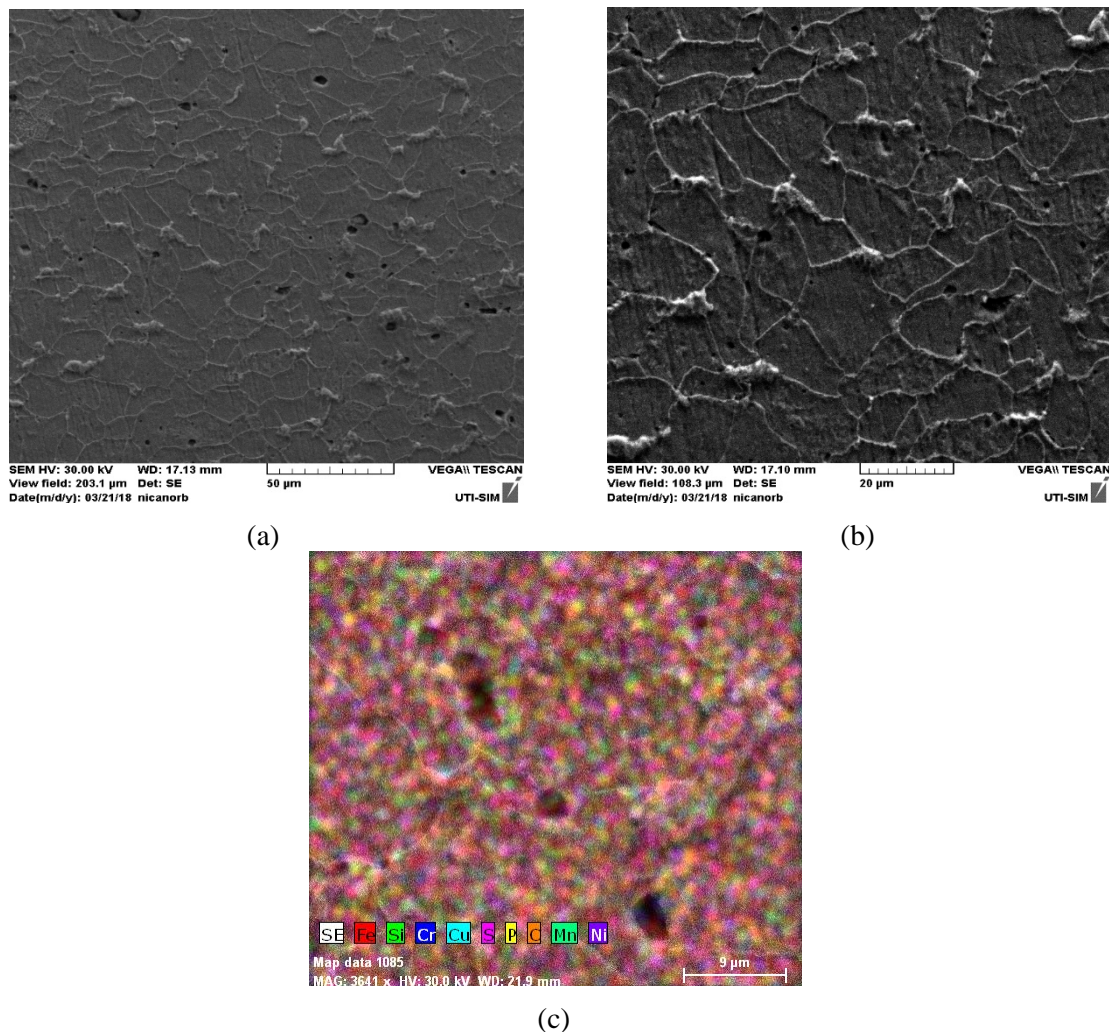


Figure 4. Carabiner material microstructure obtained using the electron scanning microscope, (a) SEM microstructure, 50 μm ; (b) SEM microstructure, 20 μm ; (c) EDX, 9 μm .

In order to obtain the standard required properties, the material high hardness and wear resistance necessary have been obtained by a final thermal treatment of quenching. The 3400 MPa surface hardness value has been obtained by Vickers test method. Quenching was followed by annealing to increase tenacity.

4. Conclusions

The material has good resistance properties (resilience) and medium corrosion resistance. For carabiner that operates under tough corrosion, wear and temperature variations, a material with better properties (or better quality material) must be used.

In order to keep the final product at a low price (not to use refractory or stainless materials), the surface properties can be improved by thermochemical treatments or coatings with metallic or polymeric substances.

5. References

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