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Materials types and selection for carabiners manufacturing: a review

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Abstract. The carabiners are vital components of fall protection systems used in a variety of areas, such as: caving, construction, arboriculture, industry, rescue / evacuation operations etc. Therefore, these metallic links play an important role in preventing work accidents which are related with fall from heights. During carabiners manufacturing, the material selection occupies an important place among the obtaining steps, because there are a high number of mechanical and chemical properties that must be possessed by the final product, in order to provide adequate user safety. This paper aims to present the manufacturing process and the main properties of the materials used for carabiners, as well as the specific advantages and disadvantages of each type of material.

1. Introduction

Over the past few years, the need to protect workers from the dangers and hazards to which they are exposed at work has led to the personal protective equipment's (PPE) creation and improvement.

This equipment is provided by the employer to be used by the worker in order to eliminate or minimize their exposure to different types of hazards (physical, chemical, biological, mechanical, radiological etc.) that can lead to occupational diseases or minor injuries, invalidity or even death [1].

The need for such equipment is established following a hazard's assessment. In workplaces where the technical measures do not provide enough protection for workers, according to the legislation they must provide them suitable personal protective equipment [2,3].

Work accidents may occur from various reasons, but one of the most common causes is related with falling from a height. Among the main factors that may cause such accidents are: personal protective equipment improperly worn or over limits wear, misuse, non-use etc. [4].

In order to prevent workers against falling from heights, in addition to the technical measures (safety nets, scaffolding), the worker is receiving personal protective equipment for fall protection, which must contain harnesses or safety belts, cables or ropes and connectors (hooks or carabiners). Prior using the equipment, the workers must be trained, in order to get knowledge about the PPE correct and safe use or regarding the occupational safety and health legislation. Therefore, a special training course about working at heights must be passed. In addition, the worker must be in good health condition supported by the medical opinion given by the occupational health physician [5].

Because of the climbing and mountaineering fast expansion, at the beginning of the twentieth century the first safety rings were invented, and few years later, Hans Friechtel invented the piton which became a mandatory accessory in climbing equipment. The carabiner was invented from the



desire of obtaining of a much suitable connecting element which can be used faster and easy in different types of situations [6,7].

The carabiners (Figure 1) are metal connecting elements that make it possible, thus are used to quickly and safely connect the components of an equipment used to work at height [8]. The personal protective system for fall protection (fall arrest system, horizontal lifeline system, netting systems, passive fall protection systems, safety-monitoring system, vertical lifeline system or rescue system) that are used in areas such as: arboriculture, navigation, civil engineering, industry (e.g. mining, petroleum), sport or utility climbing, rescue operations etc. use carabiners as main connecting elements [9-11].

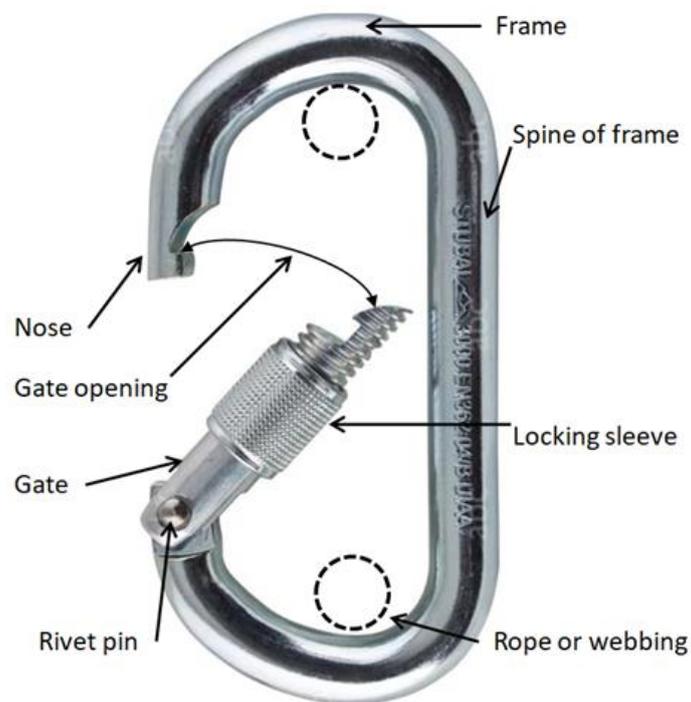


Figure 1. The carabiner components [12].

However, the carabiners are vital components of personal fall protection equipment, therefore, it has been significantly studied and improved over the years, in order to reduce the possibility of heights fall accidents [13,14]. The aim of this paper is to analyze the manufacturing process and to compare the materials used for carabiners obtaining.

2. Manufacturing materials

Although there are on the market carabiners made of special materials (such as: composite materials), usually, the materials used for carabiners manufacturing are aluminum and steel alloys [15,16]. The materials selection is mainly based on the final destination of the product, so multiple properties and factors must be taken into consideration during this stage [17-18]. Therefore, for a better understand of the choosing material stage, this paper presents a detailed comparison between the most significant properties of multiple types of metallic materials used at carabiners, namely: 7075-T6 alloy, C45 carbon steel and X₂CrNiN23-4 stainless steel.

In case of alloys the most important characteristic is its chemical composition, because it determines the structure and the main compounds from a metal. Therefore, the chemical compositions of these three materials are presented in Table 1, Table 2 and Table 3.

Table 1. Chemical composition of 7075-T6 aluminium alloy [19].

Element	Min	Max
Al	86.9	91.4
Cr	0.18	0.28
Cu	1.2	2
Fe		0.5
Mg	2.1	2.9
Mn		0.3
Si		0.4
Zr		0.25
Ti		0.2
Zn	5.1	6.1
Residuals		0.15

Table 2. Chemical composition of C45 carbon steel [20].

Element	Min	Max
Fe	97.3	99.08
C	0.42	0.50
Mn	0.50	0.80
P		0.045
S		0.045
Ni		0.40
Cr		0.40
Si		0.40
Mo		0.10

Table 3. Chemical composition of X₂CrNiN23-4 stainless steel [21].

Element	Min	Max
Fe	65.5	74.3
Cr	22	24.5
Ni	3.5	5.5
P		0.035
S		0.015
Si		1.00
Mn		2.00
C		0.030
Mo	0.10	0.60
Cu	0.10	0.60
N	0.050	0.20

Considering the fact that in mountaineering, during climbing, the fall arrest system includes a high number of carabiners and other equipment's, it is recommended to use connecting elements which are lightweight. Therefore, thus must be obtained from low density materials [13].

As can be seen in Figure 2, in these situations, aluminum is the ideal candidate as carabiner material [22-24].

A warning that carabiners manufacturing companies bring in user's attention is related to these materials drive electricity to through free electrons property, i.e. electric conductivity property [25]. The user should be informed about the electrocution possibility, in case thus get in contact with parts under high or medium voltage. Figure 3 presents the values for the electrical resistivity of these three materials, these being the inverse of the thermal conductivity. Also, it is good to know that when the temperature is low, the electrical resistivity of the material decreases [26,27].

Another property that carabiner's designers have to take into account is the material resistance to high temperatures and its thermal conductivity. If a carabiner gets in contact with various high temperature parts (e.g. when is used for removing the parts from a heat treatment furnaces) it is preferable that the conducting and transmitting heat with the help of free electrons, i.e. thermal conductivity, of the metallic part to be small [28].

Because during heating, thus material increase in dimensions, due to dilatation, the carabiner can fail by opening or disintegrate depending on the thermal expansion coefficient. According to the thermal conductivity values (Figures 4) and thermal expansion coefficient (Figure 5) steel is much suitable for the carabiners manufacture [23,24,19].

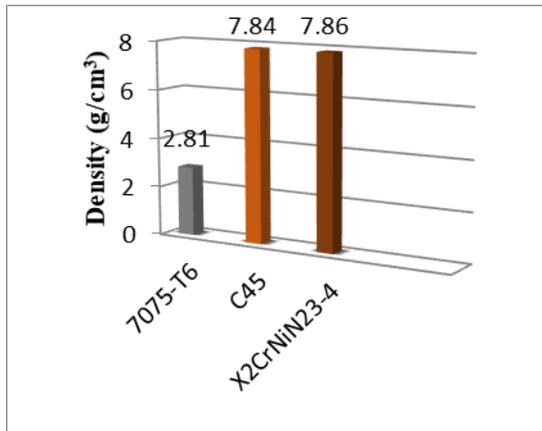


Figure 2. Density values.

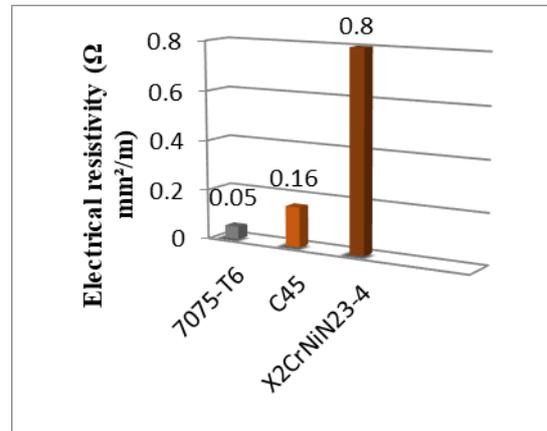


Figure 3. Electrical resistivity.

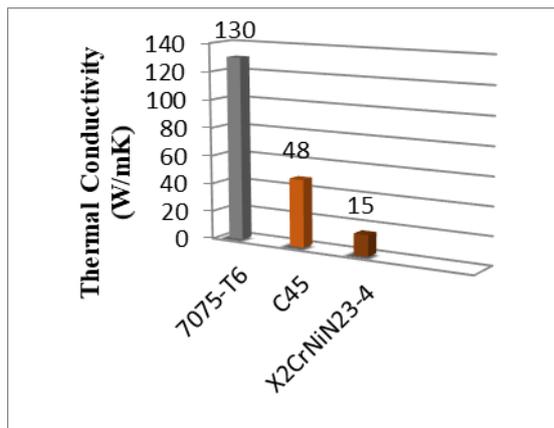


Figure 4. Thermal conductivity.

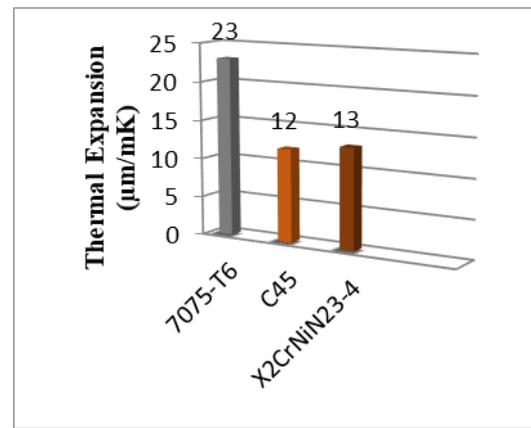


Figure 5. Thermal expansion.

In addition, some carabiners are used in environments where the temperature exceeds 500 °C (e.g. when are used by firefighters during fire extinguishing missions), therefore, it is important to know if the material properties and characteristics are affected by the working environment conditions, such as temperature.

As can be seen in Figure 6, at temperatures above aluminum alloys melting point, the steel continues to remain solid until temperatures above 1300 °C.

The materials mechanical properties are, also, important when it comes to choose the material for carabiner manufacturing. If the carabiners are drop or hit by different hard and non-deformable bodies (e.g. when thus are used in civil engineering, carabiners may be hit by hard and sharp bodies such as scaffolding or buildings edges) [29,30].

The resistance against penetration and deformation that is presented by the material from which the carabiner is made, namely its hardness, is particularly important. The hardness of the steel is higher than that of the aluminum alloy, as can be seen in the Figure 7 for 7075-T6 alloy, C45 carbon steel and X2CrNiN23-4 stainless steel [31,23,30].

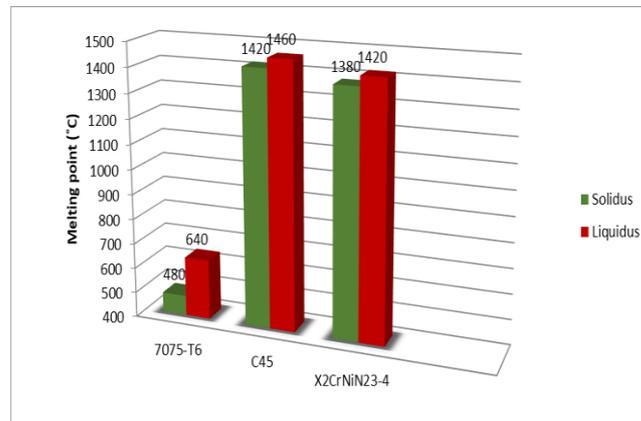


Figure 6. Softening and melting points carabiners materials.

Since these connecting elements must support high weight bodies, the material deformation under internal stress or external load and its return to the initial shape and size after unloading, i.e. its elasticity, must be studied. Figure 8 presents the elastic modulus values of these three types of materials. According to this, the aluminum alloy presents the lowest value, therefore, the mechanical shocks that will create permanent damages of the aluminum carabiner surface can pass unnoticed in case of steel [20,21,25].

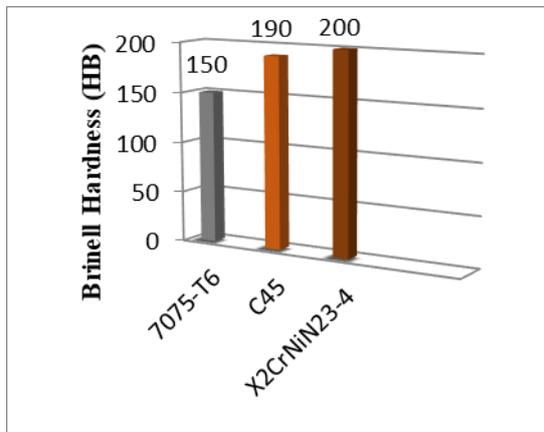


Figure 7. Brinell Hardness.

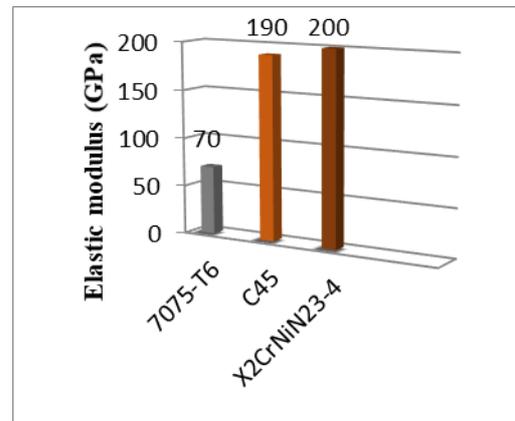


Figure 8. Elastic modulus.

According to the elongation at break values presented in Figure 9, stainless steel presents the highest value (25 %) [19,20,28]. In situations when a carabiner deformation limit is exceeded, this will present a visible plastic deformation that can be easily identified by the user. Therefore, a possible dangerous situation resulted from a carabiner failing during using at heights, which can result in severe consequences, can be eliminated.

The most important mechanical property of the materials used in the carabiners manufacture is the tensile strength [12,29,30]. As can be seen in Figure 10, the aluminum alloy withstands to higher tensile without plastic deformation (Yield), but the final tensile strength (ultimate) is higher in case of steel alloys [22-24]. The materials used for carabiners manufacturing must present ductile behavior, because in case of brittle failure, the break occurs suddenly without plastic deformation. The European Standards 12275: 2013 and 362: 2004 specify the carabiner tensile strength requirements which must be possess depending on the type of the carabiner and its destination, as can be seen in Table 4.

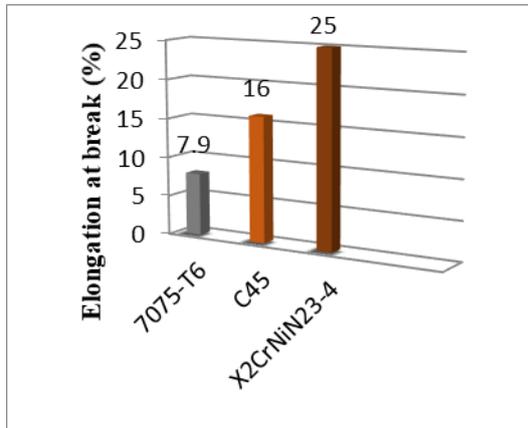


Figure 9. Elongation at break.

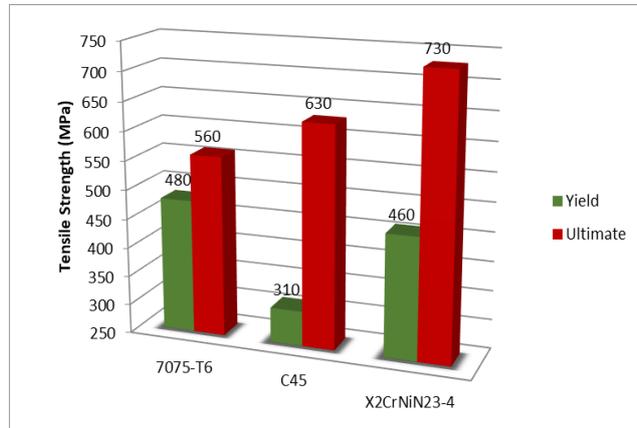


Figure 10. Tensile Strength.

Table 4. Connector types and the minimum value of the static strength required [29].

Type	Name	Scheme	R ₁	R ₂	R ₃
B	Basic connector		20KN	15KN	7KN
T	Termination connector		20KN	15KN	-
A	Anchor connector		20 KN	15KN	-
Q	Screwlink connector		25KN	-	10

R₁- static strength on major axis with gate closed and locked
 R₂- static strength on major axis with gate closed and unlocked
 R₃- static strength on minor axis with gate closed

Besides the main properties of the materials used for carabiners manufacturing, there are multiple factors, which can't be quantified, but which can influence especially durability and handling of the product, such as: surface rugosity, corrosion resistance, product handling etc. [29,30,12].

Although the aluminum carabiners are lighter and easier to handle compared to thus made of steel. In cases when the anchor point, cables or hooks are made of steel, the aluminum carabiner can be

affected by surface cracks appearance. Therefore, it is recommended to use carabiners of the same material as the other components [29,30].

Since the carabiners are used to connect, also, the textile components of the fall arrest systems, the surface of the material from which the carabiner is made must be less abrasive, in order not to cause the premature wear of these elements. Usually, the aluminum carabiners present lower rugosity compared to thus manufactured of steel [29,37].

Because the carabiners are used in a variety of environmental condition. In some situation thus can get in contact with different corrosive substances, which can result in severe consequences on the fall arrest system durability and service behavior. Another important property of the materials used for carabiner manufacturing is its corrosion resistance. By comparing thus three types of materials, the lowest value is presented by the carbon steel and the best corrosion resistance is presented by the stainless steel due to its chromium content, which naturally forms a passive layer of chromium oxide that protects the carabiner from corrosive agents. This layer regenerates itself after removing by scratching or another working situation [20,28,33,34].

Prior using the users must visually inspect the carabiners for different types of defects, such as deformations, cuts or surface cracks which can be related with dropping or hitting the connecting element by different bodies. Also, even if the carabiners do not present visual defects but it has been dropped from heights it is recommended to be replaced. Besides mechanical shocks, the material can be affected by various corrosive substances attack, if the surface presents iron oxides the carabiners must be replaced [29].

3. Manufacturing process

After choosing the materials and the final design of the carabiner depending on the application field of the product, the carabiner manufacturing process starts. According to different carabiners manufacturing companies [25,35,36] thus connecting elements are obtain through the following steps:

- The circular wire from which the most carabiners are made is bent in C shape while the materials is soft (in an annealing state).
- The relatively minor changes of the carabiners are made by hot or cold forging by means of pressing tools. While the nose profile is punched and the holes for rivets, drilled. The gates and metal sleeves are made by turning, milling or drilling.
- After the carabiner reaches the final shape, its surface must be cleaned to be as less abrasive as possible, which is important because the product can affect the durability of the assembly elements. The surfaces are sanded and polished or sandblasted by inserting the carabiner into vibratory tanks containing ceramic particles that remove all the edges sharpening, leaving the surface smooth.
- In order to obtain the necessary mechanical properties of hardness and tensile strength of the finished steel product, each carabiner is subjected to heat treatment.
- In order to improve the corrosion resistance properties of the aluminum alloys, the material is subjected an anodizing process in which an electrochemically layer, harder than that of the base material, is deposited on the aluminum surface. In the case of carbon steel, corrosion resistance is improved by zinc layer deposition or galvanization.
- After each carabiner component is ready, the specialized personnel check these elements in order to identify the functional or manufacturing faults and then the assembles stage starts.
- After the carabiner elements are assembled and it reaches the final shape, it passes through several verification stages. In order to reduce the possibility of selling carabiners which presents defects, the production is made on batches, from the moment the raw material enters in the manufacturing process until the product reaches to the final inspection. A number of carabiners in each batch are tested for tensile strength according to specific standards. According to the testing data's, a statistical quality analysis is performed in order to establish the nominal resistance of the carabiner.
- The EN 12275: 2013 standard specifies a series of markings which must be made by the manufacturer on the carabiner's body after it is assembled, thus are laser-engraved on the frame: the manufacturer's name or trademark, the carabiner type (e.g. K), the minimum value of the main axis

tensile strength in kN, tested with the gate closed and opened and the tensile strength on the secondary axis.

- The final step in the carabiners manufacturing process is to obtain an CE examination certificate in accordance with the requirements of European Union Personal Protective Equipment (PPE) Directive 89/686/EEC.

4. Conclusions

The carabiners can be manufactured from different types of materials. The materials selection must be made depending on the final desired properties of the product. By comparing the most common three types of metallic materials used for carabiners manufacturing, namely: 7075-T6 alloy, C45 carbon steel and X2CrNiN23-4 stainless steel, it can be seen that different materials presents different advantages.

The fall arrest systems used by workers or sportive includes a high number of connecting elements. Therefore, in case of mountaineering, in climbing applications, aluminum carabiners are the most suitable due to the material lightweight.

In applications that involves high temperatures steel carabiners are ideal, because this material can withstand at temperatures that will melt the aluminum carabiners. Thermal expansion coefficient can lead to product failing during using, hence it must be taken into account during designing stage.

The European Standards 12275: 2013 and 362: 2004 specify the tensile strength requirements which must be possess by the carabiners depending on their types. The ultimate tensile values of 7075-T6 alloy is 560 MPa, that of C45 carbon steel is 630 MPa and that of X2CrNiN23-4 stainless steel is 730 MPa. Therefore, in order to achieve the desired properties for the carabiner, additional heat treatments must be performed.

The carabiner surface must be as smooth as possible in order to protect the assembly components, especially thus made of textiles. Therefore, during manufacturing stage the surfaces are sanded and polished or sandblasted by inserting the carabiner into vibratory tanks containing ceramic particles.

The carabiners manufacturing process presents similar stages despite the material. Also, on the product spine are engraved the main specifications of the carabiner according to the EN 12275: 2013 standard.

Prior using the users must visually inspect the carabiners for different types of defects, such as deformations, cuts or surface cracks which can be related with service activities. Also, even if the product does not present visual defects but it has been dropped from heights or if the surface presents iron oxides the carabiners must be replaced.

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