The Al-Sc alloy in Aerospace

Scandium is the 21st element in the periodic table and is a silvery-white rare earth metal.[1] Although the amount of scandium in the Earth's crust is not small, with its abundance being ten times that of tin and two times that of lead, the fact that it is mainly produced as a byproduct of processing other ores and not scandium by itself means that extracting scandium and processing it for commercial use is very costly.[1] Thus, the global demand for scandium is relatively low.[2]

Despite these dire circumstances, people have managed to find ways to utilize scandium. One of the most important applications of scandium is its usage in aluminum alloys. This was especially true in the Soviet Union, which used the Al-Sc alloy in the aerospace industry.[3] The MIG 29 fighters are known to contain a significant amount of the Al-Sc alloy.[3] Development of the Al-Sc alloy was possible in the Soviet Union due to the USSR having access to a huge amount of Sc2O3 (scandium oxide), which made scandium easier to access compared to other countries.[1]

Scandium provides multiple advantages over other alloys of aluminum. The addition of scandium adds to the functionality of aluminum by inhibiting recrystallization, increasing tensile strength, refining grain size, reducing cracks in welds, and introducing a precipitate.

If a material reaches a temperature high enough for annealing to take place, the three annealing stages of recovery, recrystallization, and grain growth take place. All three processes can take place near the recrystallization temperature over a long period of time. Since these processes serve to decrease the tensile strength of the material, it is best for the material to not reach the temperatures at which these processes may take place. The presence of scandium is able to increase the recrystallization temperature of the alloy to over 600 degrees Celsius, which is significantly higher than that of alloys with impurities like titanium or chromium.[3] This gives the Al-Sc alloy a substantial advantage over other alloys in its applications in heat shields, fuel and exhaust systems, and other applications in aerospace where the materials have to deal with high temperatures on a regular basis.

Although aluminum is ductile and corrosion-resistant, adding impurities bolsters the strength of the material, which becomes useful in many commercial applications (in this case, building planes). Scandium's radius (184 pm) is larger than that of aluminum (118 pm),[4] which means that the addition of scandium as an impurity adds compression and reduces tensile strain. In particular, it does so by providing the largest strengthening per atom percent out of all aluminum alloys.[3] This not only serves as an advantage in the aerospace industry but also other commercial applications of the Al-Sc alloy. For instance, the Al-Mg alloy loses strength as it undergoes the process of recovering ductility and toughness. Compared to the Al-Mg alloy, the Al-Sc alloy provides a substantial amount of increase in strength, which gives it the edge over the Al-Mg alloy.

In aluminum, the equilibrium solubility of scandium can reach a maximum of about 0.4 wt%.[3] When the molten alloy is cooled to an appropriate temperature, a precipitate of Al3Sc would initially form.[3] The formation of this precipitate not only act as dislocation motion blockades (contributing to the strengthening of the material) but also help induce the grain refining effect (which also contributes to the strengthening of the material by making the dislocations lose a lot more energy as they encounter a lot more grain boundaries and have to change directions a lot more times). The precipitate does so by pinning the grain boundaries, which allows the grain size to be kept at a relatively smaller size. The advantages of strength that Al3Sc provides come in as extremely crucial in the aerospace industry, where the aircrafts have to undergo huge amounts of stress in terms of temperature, wind, and speed.

From this, it can be seen that the structural changes of aluminum in the addition of scandium allowed for certain properties to be enhanced (especially in the strengthening areas) which in turn significantly enhanced the performance of the material so that it can be applied in commercial uses like the aerospace industry. The Soviet Union recognized the superiority of the alloy over others, and given the relative abundance of scandium in its vicinity, implemented it in its aerospace industry.

While the Al-Sc possesses such beneficial traits and the USSR managed to exploit them in the aerospace industry, the lack of accessibility of scandium came as a great drawback for other countries that do not possess such a stockpile of scandium. Scandium alloys are now found usually in baseball bats or bike frames,[3] and aluminum alloys now used in aerospace usually contain copper or magnesium.[5]

References:

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