The application of ultrahigh carbon steel in the ancient Damascus blades, future of the ultrahigh carbon steel blades.

Author: Karolina Halys

Student ID: w18020784

Introduction to material

According to the legend, a technique of creating Damascus blades was firstly formed in lost continent Atlantis and brought to India when Atlantis sank [1]. In the last ages, the weapons formed in this manner were even more expensive than gold [2]. There were even rumours that this steel can even heal injuries. Among the years, due to imprecise accidents blacksmiths' lost the recipe of the art of crafting deadly weapons. Whole generations had fruitless tried to recover the way to making these blades. Thus non-oxidative properties of the material of blades the researches could be done on the original Damascus steel. Nonetheless, long ages the mystery of blades had been unsolved until the time when the scientist from Stanford University was interested in a phenomenon called 'superplasticity' in metals. In the result, an ultrahigh carbon steel with alloys of other elements has been shown to be identified as the same steel which was used to production Damascus Blades. The ultrahigh carbon steel (1.0–2.1 weight percent C) was called 'no man's land' due to suspected brittle properties in room conditions. Therefore after processed the steel demonstrate various mechanical properties (e.g. superplasticity, bigger than expected hardness, high level of strength resistance and significant ductility). This discovery was open wide spectrum interests of High Carbon Steel [3].

Reasons of choosing Ultrahigh Carbon Steel for the report of mine

I choose Ultrahigh Carbon Steel as the topic of my report not only because of interesting properties of this material but also because of being in the strict bond with the legendary Damascus steel.. Thus, Damascus steel is an ultrahigh carbon steel with superplastic properties and some – very often slightly random – alloys. The exposed of legendary steel which was one of the most mysterious materials of the past ages can change the way in which modern people are looking on the world. The world which we known is still full of questions. A famous Polish astronomer, Grzegorz Sek, used to say: 'We live in the strange world. Everyone has got their own hallucination of reality and science is – generally speaking – looking for common parts of this state.' Therefore, this report is my attempt to zoom in one of the perfectly 'matched parts' of our reality.

The method of creating

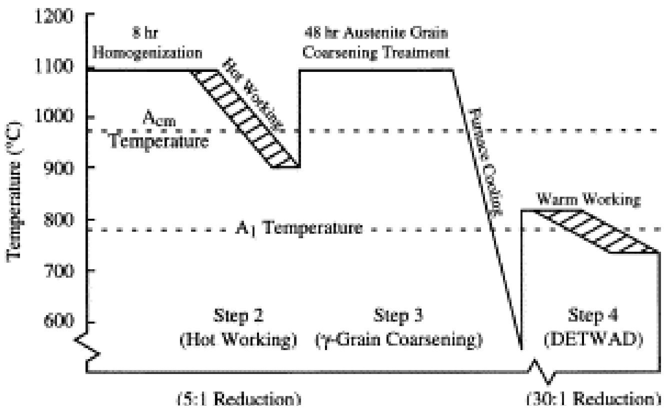

Figure 1 Procedure of creating ultrahigh carbon steel [1]

It has been proved that ultrahigh carbon steel after exact modification unveils superplastic characteristics. The research of superplasticity on ultrahigh carbon steel was firstly made on Stanford University [4]. The method, which was created as a result of these researches, has been legitimated as the possibility to fundamentally changing the industry. The main reason for that is reducing the costs of materials for over 30%. Moreover complicated shapes of supplies could be gained without wastage resources [1].

Nonetheless to subject the resource to the procedure of 4 step heat treatment some essential conditions must be fully satisfied. In the result interesting mechanical and superplastic properties are gained. The process leads to the creative product whose output characteristic attributes are different than input qualities. Moreover, structure and features might be modifying in the desired way via calibrating level of the heat on the last stage of creating.

The material should be fine-grained. Also, it should have two phases to provide the existence of the grains even in high temperature. These features, due to fine-grain structure, are allowed to process of sliding the boundaries of the source. To sum up – the grainy structure of the material gives viscous–like properties, which are fundamental to exist superplastic attribute in substance. [4] Until the time of first attempts of definition the receipt for superplasticity of materials there have been made a significant progress. The best features of the product are gained by four steps procedure called ``Wadsworth - Sherby Mechanism'' [5]. The proper schedule order is started by water-logged ingot in 1093°C during the time of 8 hours. Due to this operation presents in ultrahigh carbonated steel networks of iron-carbide 'melts and mixes' with the material in a process called homogenization. On these stage in the substance austenite grains are created (Austenite - a phase which is the toughest phase in metallurgy with a simultaneous medium quantity of ductility) [6]. In the next step the ingot is hot rolled and the temperature is decreased to 900°C. The homogenization which has been proceeded during these time has resulted more homogenous structure. The austenite grain is grown in the space between them is started to fill by accumulated carbon. The proeutectoid carbide network is started to form (proeutectoid - i.e. in a phase which is created because of cooling and the main advance of this is being more solid than austenite phase; It is contained solid with some liquid regions) [6]. Whereas further action is necessary because the carbide network had a bad influence on the properties of the substance. This is a highly undesirable but unavoidable phenomenon. Because of carbide networks, the material is more brittle, the toughness of the material is decreased and at this same time wear resistance is increased. Further furnace cooling is led to eliminating carbide network. In the last step, the material is reheated to the temperature of 810°C and hot-rolled to the temperature of 750 °C. During that process, the carbide network is interrupted and steel is very ductile and soft because of carbon in which it is enriched (Total elongation depends on the temperature of the last step of processing. The temperature, which might be various has a big influence on the further properties and microstructure of steel). The level of heat is slowly decreased because of adiabatic heating. The austenite changing the structure in process of hot-rolling several times: firstly on the pearlite and in the next stage pearlite is completely spheroidized. This is the most ductile form of the product. In the final result on the surface of the metal are created characteristic channels [7][4].

To maximize the properties of the ultrahigh carbon steel it is necessary to spray forming this material. Melted droplets of substance are poured into the cone. Before they felt down they are atomized by gas' particles. In the result, the thick layer of substance is created on the preform. [8]

Microstructure

In this part of the report, the microstructure of resource is compared with the resource after the process of spray forming. It is emphasized that both of them are after 4-step processing mentioned above.

The size of the grains for material which was processed in a basic manner is 200µm and for material after spray forming - 20µm. The space between lamellae in the first case is 0.36µm and for the second one 0.15µm. It is noticed the big scale of variances between the quantities indicates about the fine structure and higher tensile strength of steel after spray forming (The values in this paragraph are approximate). In addition because of channels on the surface of basic processed material, it is more brittle than the other one, whose surface is consistent [11].

The both of substance are contained some detritus of carbon from carbide networks. In the primary case, it is observed in the shape of semicontinuous carbide networks. These kinds of carbon concentrations do not appear in the second substance and reason is the method of creating these steel. In the result, the particles of carbon are diffused [11].

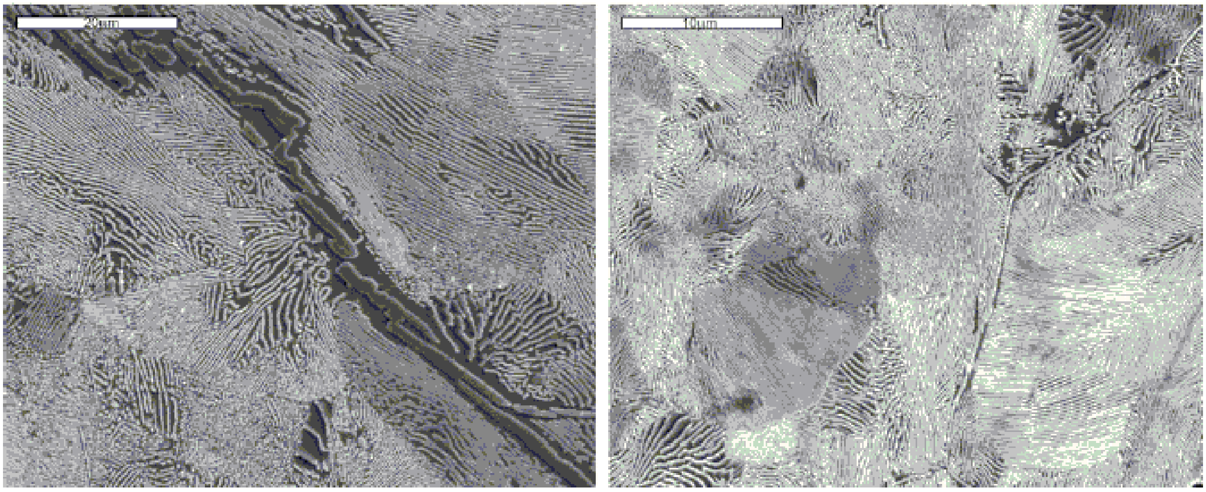

Figure 2 The microstructure of primary processed (left) and spray forged (right) ultrahigh carbon steel [11]

The temperature of hot rolling has a significant influence on the properties and structure of both materials. The space between lamellae is relatively bigger in both cases. The strict bond between them and other properties of the material are described by the Hall-Petch equation:

$$\sigma_y = \sigma_0 + k \times \sqrt{\frac{1}{\lambda}} \qquad [12]$$

Where

σ_y is the yield strength, σ_0 is the friction strength, k is the material constant and λ is the lamellae spaces (in nanometres). After rearranging this equation for λ:

$$\lambda = \frac{k^2}{\sigma_y^2 - \sigma_0^2}$$

It is assumed, that the bigger the spaces between lamellae are, the lower the yield strength is.

The level of carbide is in inverse proportion to the temperature of hot rolling. It is noticed that in the first case there are created thick, aggregated plates of spheroidized carbides and in second case carbon is mixed with lamellar structures. Despite the worse quality of material even at that moment the spray forging material have better properties than the other one i.e. there is less carbide than in first material and it is much finer. Because of these undesirable structures, the tensile strength and elongation are on a very low level in both of cases. For instance, in the further figure there are shown the structure of the material at the same temperature - 850 °C [11].

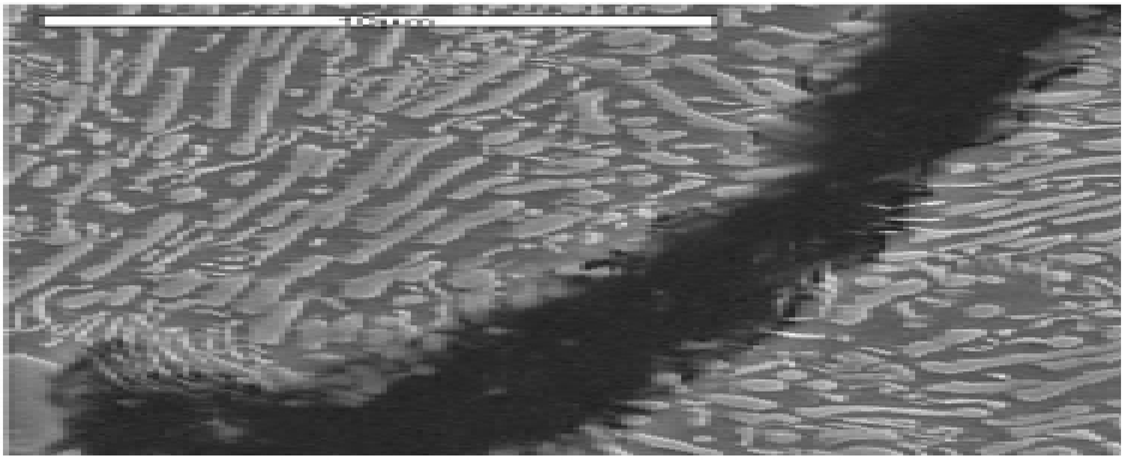

Figure 3 Structure of ordinary processed steel (left) and spray forged steel (right) in temperature 850. Adapted from: [11]

There are also proven, that in the grain boundary of ultrahigh carbon steel and carbide are created microcracks, i.e. the weakest points of the material. Consistency might be interrupted and propagated along these places [11].

Mechanical properties

Tensile properties of material achieved in different manners, and described in the previous part of this report, are presented in the table below.

Name of processing	Temperature of hot rolling in (°C)	Yield strength (MPa)	Tensile strength (MPa)
Standard	1100	1005	1334
Standard	850	928	1031
Spray Forging	1100	1216	1552
Spray Forging	850	1063	1295

Table 1: Tensile properties of material processed in different manner in various temperature. Adapted from:[11].

(Standard processing – material only after main processing.)

It is noticed that with a decreased temperature of hot rolling, yield strength and tensile strength is appropriately lower. In the meantime, stress-strain reliance is not so intuitive. It is proven that material which is heat-treated in the lower temperature has a surprisingly high level of toughness. On following figure materials processed in heat 770°C and another one which was homogenized in temperature 1150°C are compared. The fracture strength, in this case, is equal to 4500 MPa. Both of these steels have similar hardness and the same carbon content. It is noticed that the second one fracture strength is equal only 3000°C [9].

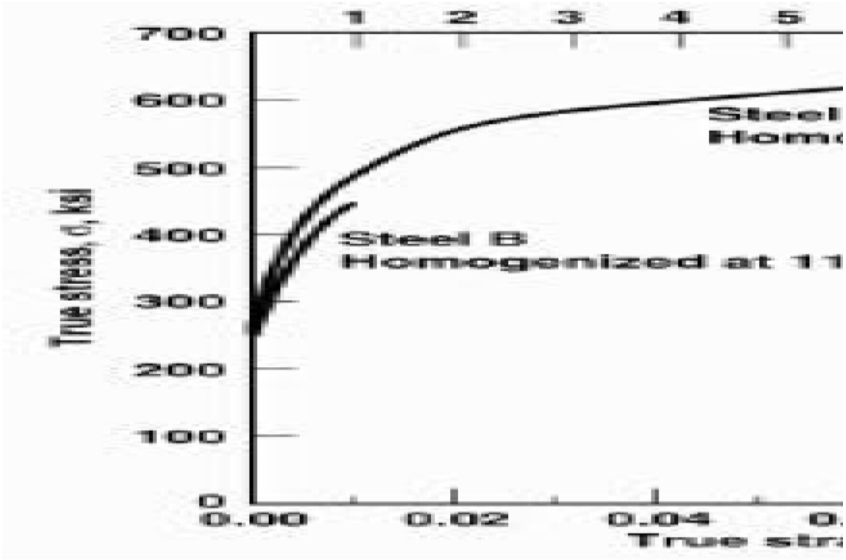

Figure 4 Stress-strain curve of steel processed in different manner [9]

Superplasticity, which was mentioned earlier as the primary factor in the development interest of ultrahigh carbon steel is one of the best and the most unique features of the product. Thus, ultrahigh carbon steel might be very superplastic during processing and at the same time ductile and strong at room temperature. The best properties are shown in the heat 700°C. Elongation to failure is varied between 600% and 1000% at strain rates $10^{-3}s^{-1}$[1].

It is proven that material enriched in other alloys (most popular ones are aluminium and silicon) have a higher quantity of elongation. Choose of these elements are determined by the following fact. It is strictly stated border for the temperature of heat treatment in the creating process. When a proper level of warm is achieving austenite grains grows and carbide wanes. When the small amount of alloy is being added the border is moved to higher values. Therefore, the formations mentioned earlier can continue the expansion above the standard border and maximum of the superplastic structure is achieved. Moreover, the content of aluminium in substance leads to very high antioxidant properties. It is proven that this material can endure a temperature of 1200°C for a long time without damage. Thus, identification of the Damascus steel is guided on the original blades [1].

Strengths and the weaknesses

Despite passing ages, Damascus blades, which are created from ultrahigh carbon steel are still very precious. This is because the production of ultrahigh carbon steel is very complicated and since the method for commercialisation is unknown. However, first attempts had been made by creating an economical method of forming. Lawrence Livermore National Laboratory government-industry consortium has been nearly achieved essential condition to produce the ultrahigh carbon steel with high aluminium alloys. Nonetheless, manufacture never was implemented since the majority of billets were fractured during casting. [4]

The proof for the excellent strength, sharpness and durability is the splendid fame of these blades. Reason for that is following: straight steel (i.e iron) is not a fully appropriate material for swords. An ideal weapon should be hard enough to deliver powerful hits without wastage of sharpness. And losses of sharpness for are crucial in this case. Damascus steel was perfect for the good blades and even more than that, since superplastic properties which resulted in big durability. The armoured enemy can be deadly harmed by one cut. And the weapon was nearly indestructible on the battleground.

Conclusion

The ultrahigh carbon steel as a Damascus steel is a very important part of European culture. The quantity of interesting attributes of the material is rare. However, a complicated process of creating as well as fact that currently substances with better properties are known, making this material almost useless in the modern days. Notwithstanding for me it is charming to see this subtle union between reality and legend.

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(including title, text and captions)

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