PAPER • OPEN ACCESS

A significant review on different cooling agent during rapid cooling process of low carbon steel

To cite this article: M A Mohd Saaroni *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **736** 022118

View the article online for updates and enhancements.

This content was downloaded from IP address 103.53.34.18 on 05/03/2020 at 07:28

IOP Conf. Series: Materials Science and Engineering **736** (2020) 022118 doi:10.1088/1757-899X/736/2/022118

A significant review on different cooling agent during rapid cooling process of low carbon steel

M A Mohd Saaroni[1], N Sazali[1,2]*, and M F Ghazali[1,2]

[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2]Centre of Excellence for Advanced Research in Fluid Flow (CARIFF), Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia

*azlianie@ump.edu.my

Abstract. Low carbon steel has been chosen as the engineering material in this project to research the comparison of the effects of cooling agent during rapid cooling process and to develop a mechanical data of low carbon steel after the heat treatment. This material has been chosen because it is mostly used for deep drawing of motor car bodies, motor cycle parts and other domestic applications where it need to involve the desired mechanical properties processes. Rapid cooling process or quenching is common process to obtain certain material properties such as increasing strength and hardness. This process is widely used in industry to obtain required properties of any application.

1. Introduction

Low carbon steels comprise principally of ferrite, which is a solid solution stage of carbon diffused in alpha-iron, a body centred cubic crystal. Ferrite is the softest state of steel which is to a great extent in charge for the greater machinability of low carbon steel with respect to other alloyed and carbon steels. As the carbon content increases in the steel, an increasing amount of pearlite is formed in the microstructure of the metal. Pearlite is a tiny part comprising of different layers of iron carbide and ferrite [4]. Low carbon steel is known as low carbon steel is a standout among the most broadly recognized sorts of steel utilized for general purposes, to some degree since it is regularly more affordable than different kinds of steel. While the steel contains properties that function admirably in assembling an assortment of products, it is mostly made into flat-rolled sheet or strips of steel. In order to make parts effectively manufactured in formable soft state, steel need to be heat-treated. If sufficient carbon is available, the alloy can be hardened to improve impact resistance, strength and wear. Steels are regularly created by cold-working process, which is the forming of metal through deformation at a low or met a steady temperature.

Process of manufacturing ventures can be improved by the understanding of microstructure's characteristics of material used. Metals regarded as the most suitable material in this case where their material properties are determined by various tests. As a mechanical engineer, it is required to participate in testing work to share better comprehension for all intents and purpose of properties test for metals. From engineering perspective, mechanical properties are the most significant necessity in choosing material for configuration reason. Mechanical properties and microstructure of metals depict

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

their conduct under mechanical and physical use. Metallic materials, for example, steel have numerous applications where both high strength and great ductility are required. However, the strength and ductility are fundamentally unrelated for most metals and alloys [15]. Plenty of studies have been done on metal, so the microstructures of most metals are well identified as well as the impacts of heat treatment in modifying their mechanical properties. Carbon steel is among the type of metal been used in the industry. Carbon steel is divided into three categories as indicated by their carbon content. The categories are low or mild carbon steel, medium carbon steel and high carbon steel. Respectively to its relative strength, carbon steel is widely used in automotive and industrial applications.

Rapid cooling is a process purpose to harden the metals by drenching in oil or water, of a metal article from the high temperature at which it has been formed. This typically is attempted to maintain mechanical properties related with a crystalline structure or phase dispersion that would be lost upon slow cooling. The technique is normally applied to steel objects; to which it gives hardness. Then again, copper objects that have turned out to be hardened by hammering or other deformation at conventional temperatures can be re-established to the malleable state by heating and quenching [12].

2. Heat treatment process

A combination of times heating and cooling tasks which used to the solid state metal or alloy is known as heat treatment. This technique is frequently used to adjust the properties and microstructure of steels. The different kinds of heat-treating procedures are comparable because they include the heating and cooling of metals. However, the heating temperatures and the cooling rate applied are different. The final results of each method are different. The typical methods of heat-treating ferrous metals are tempering, annealing, hardening and normalizing. Most nonferrous metals are applicable to annealing, however never case-hardened, tempered or normalized [5]. According to [6] heat treatment cannot change metal shape, rather only to change their physical and mechanical properties through heating and cooling processes. Heat treatment is likely to be a process for strengthening materials however could likewise be utilized to change some mechanical properties for example increasing machining and formability. The mostly known method is metallurgical however heat treatment can also be done in assembling of steel, aluminium and glass. The procedure of heat treatment includes the utilization of heating and/or cooling, normally to utmost temperatures to accomplish the needed outcome. Heat treatment is a very significant manufacturing process that can be a big help to manufacturing process by enhance the product, its attributes, and its performances from various perspectives.

3. Normalizing process

This process can be done by heating the steel to austenite phase and then cooling it in the open air. In industry, normalizing is applied to take out coarse-grained structures acquired in past working processes, for example, rolling and forging. According to [1] normalizing is purpose to adjust and improve the cast dendritic structures and lessen isolation by homogenizing the microstructure. The ideal mechanical properties and microstructure can be obtaining to improve the machinability of low carbon steel. In normalizing, a total transformation of austenite occurs when the steel is continuously heated to certain temperature. Steel is held at this temperature for enough time for the development of homogenous structure all through its mass. Then it is permitted to cool in open air in a consistent way. Air cooling will give faster rate of cooling when compared to furnace cooling rate. Thus, the normalizing cooling time is radically lesser to annealing.

Plastically deformed steel by a rolling processes, contain of pearlite grains and a proeutectoid phase, which are unpredictably formed and generally huge and change considerably in size. Normalizing which is type of annealing heat treatment is utilized to refine the grains and produce a progressively consistent and desired size distribution; fine-grained pearlitic steels are harder than coarse-grained pearlitic. At least 55°C above the upper critical temperature, normalizing can be perform, that is, above A_3 for arrangements not exactly the eutectoid, and for arrangements larger than the euctectoid, above A_{cm}. After enough time allowed for the alloy to change totally into austenite, a process called austenitizing then took part, the procedure is ended by cooling in still air [14].

4. Quenching process

Quenching is fast cooling with cooling media including water, oil and other chemically compounds. Frequently applied medium in industry is liquid quenching as it outfits a quenching process with homogenous and increasingly controllable transfer of heat from the hot specimen [8]. Quenching is broadly used nowadays to improve steel components which is hardness by the arrangement of a totally or predominantly martensitic microstructure. The process includes beginning heating stage which range from 850 to 900 °C, depending on type of steel to advance homogenous austenite arrangement then rapidly cooled to room temperature. This step is usually conducted by immersion in liquid baths. At present, mineral normally petroleum-derived oils are commonly used for quenching process because of their sufficient cooling rates in order to prevent the development of softer and unwanted microstructure constituents which are pearlite and ferrite, while keeping away from cracks or distortions in the steel, which may emerge in extreme cooling medium [9].

4.1. Slow cooling of hypoeutectoid steel

At point d, about 775 °C, which is inside the $\alpha + \gamma$ phase region that exist together as in the schematic diagram. Almost all of the small α particles structured along the actual γ grain boundaries. The ferrite (α) and y phases will exist together at $\alpha + \gamma$ phase region as in Figure 1. The greater part of the little α particles will structured along the actual y grain boundaries. When alloy is cooled through the $\alpha + \gamma$ phase region, the compositions of the ferrite phase transforms according to temperature along the α – (α+ γ) phase boundary. The *MN* line is ending up somewhat contain more carbon. Then again, the adjustment in composition of the austenite will become significant while moving along the (α+ γ) -γ boundary shown in line *MO*, temperature is decreased.

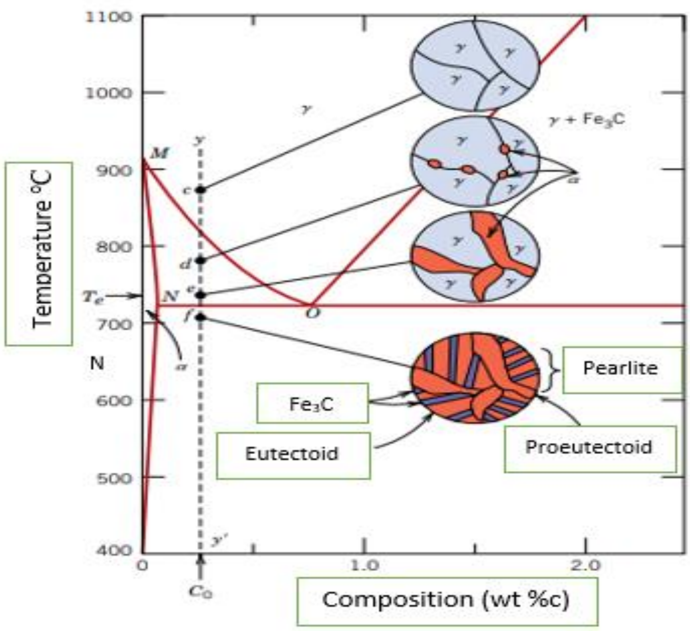

Figure 1. Hypoeuctectoid steel.

Furthermore, when the steel is continuously cooling from temperature d to e, the measure of proeutectoid ferrite structures will increment until about half of y is changed. From e to f, the steel is being cooled thus the content of carbon on the remaining austenite will be expanded from 0.4 to 0.8% of C. At temperature of 723 °C which is eutectoid temperature, the rest of austenite will transform isothermally into pearlite by the eutectoid reaction. The ferrite (α) in the pearlite generally called as eutectoid ferrite. Besides, as the temperature is brought below enough the eutectoid to point f, the α

phase that was available at temperature point e will change to pearlite. Nothing will change in the α phase at point e in intersecting the temperature of eutectoid; it will typically be available as a continuous matrix phase enclosing the secluded pearlite groups. In this way, the ferrite phase will show up in the pearlite as the phase that formed when cooling along the $\alpha + \gamma$ phase region [14].

5. Microstructure theory

Low carbon steel with different process of heat treatment will give different microstructure of steel. The structural features of steel under microscopic condition will be represented by its microstructure. The study of microstructure is also called microscopy or metallography. Almost all of the phase transformations of interest will include deviations from balance microstructures, bringing about incomplete transformations and the reaction of metastable phases. The microstructure of iron-base alloys is very complex and differing, being impacted by chemical composition, material homogeneity and section size [13]. According to [3], as the steel gradually cools from this temperature and carbon is constrained out of solution, the austenite changes into a mix of ferrite and another stage called cementite, otherwise called iron carbide, which has the synthetic organization of Fe3C. The measure of cementite that structures is a component of how much carbon is in the steel. Since ferrite cannot contain more than around 60 PPM carbon at room temperature, the remainder of the carbon ends up as cementite.

6. Testing on mechanical properties

6.1. Hardness test

Hardness is characterized as the material resistance to permanent deformation such as wear, scratch, indention and abrasion. Basically, the significance of hardness testing relates between hardness and other properties of material. As example, the measure of both hardness test and tensile test are conducted by the resistance of a metal to plastic flow, and basically will give results that firmly parallel to one another. The hardness test is favoured because it is basic, easy and generally non-destructive. The hardness test is a mechanical test for material properties which are utilized in engineering design, materials progress, and analysis of structures. The truly reason for the hardness test is to decide the suitable material for given applications, or the specific treatment suited with desired material. The simplicity of the hardness test can be done has acknowledge it to be the most frequently used method for inspection of metals and alloys. Since the method used to build the strength of a material for example, heat treating, alloying, or mechanical working also increase the material hardness, hardness measurements can give a fast and simple means to check if a given strength has been achieved through a specific process [14].

6.2. Rockwell hardness test

The Rockwell tests comprise the most usual method to use in indicating hardness since they are very easy to execute and does not require any special skills. Possible combinations of different indenters and different loads of few various scales may be used for a process that allows the virtual test of all metal alloys including a few polymers. Spherical and hardened steel balls indenters with diameters of 1.588, 3.175, 6.350, and 12.70 mm, respectively, which is utilized for materials with highest hardness. According to this system, the number of hardness is indicated by the difference in depth of penetration resulting from the application of an initial minor load followed by a larger major load; test accuracy is improved with the use of minor load. The test is divided according to the basis of magnitude of both minor and major loads, which are Rockwell and Superficial Rockwell.

The minor load for Rockwell test is 10 kg, while its major loads are 60, 100, and 150 kg. Letter of the alphabet are used to identify each scale. Both hardness number and scale symbol need to be shown when determining Rockwell and superficial Rockwell hardness. The scale is assigned by HR symbol pursued by the identification of fitting scale. As example, 100 HRB indicated a Rockwell hardness of

100 on the B scale, and 80 HR 20W shows a superficial hardness of 80 on the 20W scale. The occurrence of inaccuracies will happen if the test sample is too thin, if an indentation is made too close with the edge of specimen, or if two indentations are made excessively near each other. Specimen thickness ought to be at least ten times the indentation depth, whereas allowance should be considering for at least three indentation diameters between the centre of one indentation and the specimen edge. Besides, stacking of specimen one over another is not suggested. Accuracy is also reliant on the indentation being made into a flat and smooth surface [14].

7. Heat treatment effects of low carbon steel

Carbon steels with an assortment of microstructures are used as bars, plates and wires because of their unrivalled mechanical properties, for example, quality, flexibility and sturdiness. A mix of heat treatment and alloying components gives a suitable microstructure, and the ideal mechanical properties can be acquired. In any case, in the heat treatment of carbon steels, alloying components are in some cases isolated at the microstructural boundaries [7].

The purpose of hardening is to improve the specimen hardness and so the hardness number will be bigger than annealing and normalizing since carbon do not get enough time to react with oxygen for fast rate of cooling, the development of martensite happen because carbon is caught inside the specimen. Once more, annealing retains ductility and eliminates internal stresses but its hardness number is smaller than hardening because carbon will get enough time to react with oxygen from surrounding for slow rate of cooling and normalizing cannot retain ductility as much as done by annealing. Hardness number in annealing will be greater but lesser than hardening. The changes of austenite to soft pearlite happen when conducting slow cooling in annealing and furthermore increases the brittleness of the steel when cementite or ferrite is mix with it. The transformation of soft steel to moderate hard steel occur in normalizing. In this situation rate of cooling is faster than annealing. Therefore, ferrite and cementite are formed in a small quantity when the specimen is cooled in room temperature. When the brittleness is decreased, the ductility of specimen will increase. In hardening process, the structure of austenite is immediately transformed into martensite structure after fast cooling. Literally the fast cooling change almost all of the austenite into martensite which have a hard structure and more stable than austenite at normal temperatures. Because of hardening, the structure will have a super saturated solid solution that trapped carbon in a body centred tetragonal structure called martensite which added the steel specimen’s hardness number radically making an extremely hard steel [11]. Heat treating in industry generally being refer to the heating and cooling operations done on the metal workplaces to alter their metallurgical structure, mechanical properties or their residual stress state. Heat treating involve normalizing, stress-relief treating, annealing, hardening, austenitizing, quenching, tempering, cold treating martempering and austempering

8. Conclusion

The effect of different cooling agent during rapid cooling process on low carbon steel has been reviewed. Many researchers stated that different cooling agents can affect the microstructure of the steel as the cooling rates are varies and played an important role on the result. Low carbon steel is a kind of carbon steel with a low measure of carbon. Although ranges vary depending on the source, the amount of carbon normally found in low carbon steel is 0.05% to 0.25% by weight and a manganese content that falls in the range of 0.40% and 1.5%. This review is being undertaken to compare microstructure effects of cooling agent on metal in rapid cooling process.

Acknowledgement

Authors would like to extend their gratitude to Ministry of Higher Education Malaysia and Universiti Malaysia Pahang (UMP) with grant number RDU192615.

References

[1] Agrawal B K 1992 Heat treatment of steel *Introduction to Engineering Materials* (New Delhi: Tata McGraw-Hill Education) pp 116-117
[2] Carola C-C, Jilt S, M J Santofimia 2019 *Materials and Design* **167** 107625
[3] Daniel J S 2016 *A review of steel microstructure.* Retrieved from https://www.thefabricator.com/article/metalsmaterials/a-review-of-steel-microstructures
[4] Evans R 2012 *Metalworking Fluids (MWFs) for Cutting and Grinding* 23-78
[5] Fred A C 1997 Maintenance procedure *Basic Optics and Optical Instruments* (Dover Publication) pp 7-25
[6] Johnsinit 2018 *What is Heat Treatment? Hardening, Tempering, Annealing, Normalizing, Carburization, Surface Hardening* Retrieved from https://www.brighthubengineering.com/manufacturing-technology/30476-what-is-heat-treatment/
[7] Kadowaki M, Muto I, Katayama H, Masuda H, Sugawara Y and Hara N 2019 *Corrosion Science* **154** 159-177
[8] Allazadeh M R 2009 *The Effect of Cooling Rate on the Microstructure Configuration of Continuously Cast Steel Slabs* (PhD Thesis: University of Pittsburgh)
[9] Brito P, Ramos P A, Resende L P, Antonio de Faria D, Ribas O K 2019 *Journal of Cleaner Production* **216** 230-238
[10] Roger N W 2016 *Wire Technology (Second Edition): Process Engineering and Metallurgy* (Oxford: Butterworth-Heinemann)
[11] Mahbobur Rahman S M, Karim K E and Shahriar Simanto M H 2016 *Applied Mechanics and Materials* **860** 7-12
[12] The Editors of Encyclopaedia Britannica 1998 Quenching *Encyclopædia Britannica* Retrieved from www.britannica.com/technology/quenching-materials-processing
[13] Vander Voort G F 2005 Microstructure of Ferrous Alloys Totten *Analytical Characterization of Aluminum, Steel, and Superalloys* eds D.Scott MacKenzie & George E. (Boca Raton, Florida: CRC Press) p 157
[14] Callister W D and Rethwisch D G 2014 *Materials Science and Engineering: An Introduction* (Hoboken, New Jersey: Wiley) pp 324-369
[15] Shi Y, Li B, Gao F, Wang L, Qin F, Liu H and Li S 2019 *Materialia* **5** 100181
[16] Li Y J, Li X L, Yuan G, Kang J, Chen D and Wang G D 2016 *Materials Characterization* **121** 157-165