Brazilian Journal of Development

Investigation on the Capacity of PVP Polymer in 15B30 Steel Cooling in the Quenching Process

Investigação sobre a Capacidade do Polímero PVP no Resfriamento de Aço 15B30 no Processo de Têmpera

DOI:10.34117/bjdv6n7-610

Recebimento dos originais: 03/06/2020
Aceitação para publicação: 23/07/2020

Eduardo da Rosa Vieira
Doutorando em Engenharia Mecânica
Programa de Pós-Graduação em Engenharia Mecânica (PROMEC) - UFRGS
Rua Sarmento Leite, 425 - Sala 202, Centro Histórico - 90040-001, Porto Alegre - RS
vieira.r.eduardo@hotmail.com

Jorge Luis Braz Medeiros
Professor da Universidade Federal do Rio Grande (FURG)
Programa de Pós-Graduação em Engenharia Mecânica (PPMec) – FURG
Av. Itália, Km 8, s/n, Carreiros – CEP 96203-900, Rio Grande – RS
jorge.braz@furg.br

Luciano Volcanoglo Biehl
Professor da Universidade Federal do Rio Grande (FURG)
Programa de Pós-Graduação em Engenharia Mecânica (PPMec) – FURG
Av. Itália, Km 8, s/n, Carreiros – CEP 96203-900, Rio Grande – RS
lucianobiehl@furg.br

Vagner Machado Costa
Professor do Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Sul
Rua. Engenheiro Alfredo Huch, 475 - CEP 96201-460, Centro, Rio Grande – RS
vagner.costa@riogrande.ifrs.edu.br

Lediana dos Santos Nunes
Professor do Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Sul
Rua. Engenheiro Alfredo Huch, 475 - CEP 96201-460, Centro, Rio Grande – RS
lediana.nunes@riogrande.ifrs.edu.br

Eder Hermes Bicharra
Mestre em Engenharia Mecânica
Programa de Pós-Graduação em Engenharia Mecânica (PPMec) – FURG
Av. Itália, Km 8, s/n, Carreiros – CEP 96203-900, Rio Grande – RS
ederbicharra@gmail.com

Marcos Saalfeld da Silva
Mestre em Engenharia Mecânica
Programa de Pós-Graduação em Engenharia Mecânica (PPMec) – FURG
Av. Itália, Km 8, s/n, Carreiros – CEP 96203-900, Rio Grande – RS
marcosaalfeld@gmail.com

RESUMO

O polivinilpirolidona é um polímero solúvel em água, o qual vem sendo utilizado para arrefecimento dos materiais em tratamentos térmicos de têmpera. A têmpera consiste em fornecer calor ao metal até que ele seja completamente austenitizado, alterando sua rede cristalina para cúbica de face centrada. Então, ele é imerso em um fluido para que resfrie rapidamente. O fluido usado precisa ter capacidade de troca de calor suficiente para evitar que carbono seja difundido, assim, desenvolvendo uma rede cristalina tetragonal de corpo centrado, formando martensita e promovendo alta dureza e resistência mecânica ao material. A diluição do PVP em água, promove maiores taxas de resfriamento. Sendo assim, as máximas concentrações mais utilizadas de forma comum são de aproximadamente 30% para aços de maior temperabilidade e em 10% de baixa temperabilidade. Quando aplicados para o arrefecimento de aços carbono, com médio e alta quantidade de carbono, os polímeros não diluídos ainda não apresentaram resultados satisfatórios para a formação de martensita. Desse modo, o trabalho investigou a capacidade de resfriamento do PVP quando aplicado em aços AISI 15B30. Então, foi verificado que mesmo em aços desse tipo o polímero em 100% de concentração não é indicado para o processo de têmpera, visto que não desenvolve taxas de troca térmica suficiente para a transformação sem difusão de carbono.

Palavras-chave: têmpera, fluidos de têmpera, PVP, aço 15B30.

ABSTRACT

Polyvinylpyrolidone is a water-soluble polymer, which has been used to cool materials in tempering heat treatments. Quenching consists of providing heat to the metal until it is completely austenitized, changing its crystalline network to face-centered cubic (FCC). Then, it is immersed in a fluid that it cools quickly. The fluid used must have sufficient heat exchange capacity to prevent carbon being diffused, thus developing a body-centered tetragonal (BCT) crystalline network, getting martensite and promoting high hardness and mechanical resistance to the material. The dilution of PVP in water, promotes higher cooling rates. Therefore, the maximum concentrations most commonly used are approximately 30% for steels of greater hardenability and 10% for low hardenability. When applied to the cooling of carbon steels, with medium and high amount of carbon, the undiluted polymers have not yet presented satisfactory results for the formation of martensite. Thus, the work investigated the cooling capacity of PVP when applied to AISI 15B30 steels. So, it was found that even in steels of this type, the polymer at 100% concentration is not suitable for the quenching process, as it does not develop sufficient heat exchange rates for the transformation without carbon diffusion.

Keywords: quenching, quenching fluids, PVP, 15B30 steel.

1 INTRODUÇÃO

The application of aqueous polymeric solutions in the cooling of steels during the heat treatment of quenching is gaining ground in the mechanical industry because these fluids have several advantages over traditional fluids [1]. In general, this treatment, which aims to change the microstructure of the material through heating followed by rapid cooling, uses mineral oil, water or saline solutions as a cooling medium [2,3]. These fluids can present process difficulties, related to the inadequacy of cooling rates, which have consequences from the inability to carry out the treatment to the unusable parts. In addition, there are some specific situations that discourage use, especially related to health and the environment [4]. Although little discussed in the technical field of engineering, the use of more sustainable strategies in construction are important factors not only in the environmental aspect, but also in the technical and economic improvement of projects [5].

The quenching heat treatment basically consists of heating the metal to a temperature at which it develops austenitic microstructure. Then, the material is inserted into a fluid at room temperature, cooling it quickly. This sudden change in temperature must be fast enough so that carbon diffusion does not occur, and a martensitic microstructure is obtained, which has a body-centered tetragonal (BCT) crystalline network. This microstructural change promotes a high increase in hardness and mechanical resistance, to the detriment of toughness. Thus, very low heat exchange rates, fail to cool the material fast enough, forming unwanted microstructures and not being successful in the process [3,6].

The cooling process is divided into three stages. In the first phase, we have the heated material's contact with the liquid fluid, which causes evaporation. This layer of steam surrounds the part and prevents heat exchange with the fluid. Therefore, there is low thermal exchange in that first instant. As soon as the thermal energy of the part is not high enough to vaporize the liquid, boiling starts [7]. n this second stage, air bubbles form that detach from the part and rise to the surface, causing the highest heat exchanges in the entire process and considerably reducing the body temperature. Finally, the boiling phase ends and convection begins, in which the piece is at a lower temperature and is unable to cause a further change of physical state in the fluid or in the crystalline network. Again, heat exchange rates are reduced, and the phase lasts until the material is in thermal equilibrium with the fluid [8].

One of the most important factors in the process is the breaking of the steam film, which characterizes the change from the initial phase to boiling. In most fluids, this vapor layer extinction occurs gradually, starting at the bottom of the material and gradually evolving to the top [3]. It is important to comment that the change from austenite to martensite causes an expansion of the crystalline network, between 2 to 4%, depending on the alloy elements contained in the steel [9]. This increase in the network causes the first cooled parts of the piece expand and compress the rest of the body, developing residual tensile and compressive stresses at the end of the process. These stresses, when they have high magnitudes, can trigger plastic deformations and, in more extreme cases, cracking in the pieces [10,11].

The aqueous polymeric solutions, which are a homogeneous mixture of polymers in water, have a different mechanism during cooling. Instead of a gradual breakdown of the vapor blanket, in polymeric fluids there is an instantaneous collapse in the entire layer. Because of this, there is no gradient of thermal exchange throughout the body, which results in minimized residual stresses and greater uniformity of properties throughout the part. These solutions present high flexibility in the process, since the concentration of polymer in the water considerably alters the heat removal capacity of the material [12]. The increase in concentration causes loss of heat exchange capacity, since they increase the viscosity of the refrigerant, because they make the vapor layer thicker and more stable. Very low concentrations approach the characteristics of the heat exchange coefficient of water; however, it maintains the form of collapse of the vapor layer of the polymers. As additional advantages, these fluids are non-flammable and have low toxicity [13].

The use of high concentrations of aqueous polymeric solutions is not widespread. As it develops low cooling capacity, its application is not possible for all types of steels. The application of concentrations of 75 and 100% of polyalkylene glycol (PAG) in AISI 1040 steels demonstrated the inability to form martensite, resulting in a predominantly bainitic microstructure. When the same experiment was applied to AISI 1080 steel, it was demonstrated that the 75% solution developed a material with only 31% martensite, whereas the undiluted solution formed only 6% [13]. In turn, the povinylpyrolidone polymer (PVP) differs from other fluids because it develops a vapor film that is more unstable and susceptible to breakage, reducing the time needed for the first stage of quenching [14]. Like the other representatives of the polymers, the PVP showed a variation in heat removal from the part according to the variation in concentration. In addition, the application in concentrations of up to 25% demonstrated effectiveness in cooling low alloy steels [15]. AISI 15B30 steel is a Boron steel that, although it does not have a high amount of carbon, has considerable conformability due to the presence of Boron in its chemical composition, which improve its hardenability too [16]. This work aims to investigate the cooling capacity of PVP with 100% concentration in cooling AISI 15B30 steels in the quenching process.

2 MATERIALS AND METHODS

Before the treatment was carried out, the material was exposed to spectrometry, in order to ensure that its chemical components were within the specified limits for steel.

Then, the material samples were sectioned in flat plates, forming a square with dimensions of 10 x 10 mm, and thickness of 3 mm. This material was exposed to a temperature of 880 ° C in a resistive oven, guaranteeing its austenitization. After heating, the pieces were immersed in a 5000 cm^3 container containing PVP without dilution in water. Also, it is important to specify that there was no stirring of the PVP inside the container, ensuring that the fluid was static during the process.

After that, the samples were prepared for metallography. From this, two points were evaluated: one near the surface and the other near the center of the samples. This evaluation was performed by an optical microscope, with a 100-fold magnification, in which images were obtained to verify the microstructure.

3 RESULTS AND DISCUSSION

From the spectrometry, it is possible to observe the quantities of chemical elements that make up the material. The results are shown in Table 1.

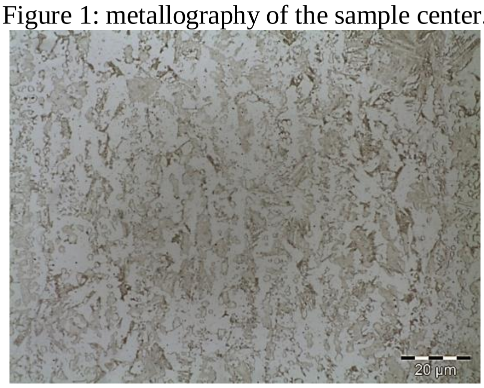
Table 1: steel spectrometry results

AISI 15B30											
Element	C	Mn	Si	Ti	B	P	S	Cr	Mo	Ni	Cu
Measured	0,312	1,161	0,205	0,0481	0,0027	0,00102	0,0018	0,0143	0,0026	0,132	0,128
Limits	0,27 - 0,35	1,15-1,5	0,15-0,35	0,01-0,06	0,0005-0,003	0,003 max	0,0025 max	0,20 max	0,06 max	0,30 max	0,25 max

As shown in Table 1, we verified that there is an adaptation of the material to the limits compared with the results of Restrepo, H.S. (2001) [16]. Thus, it was ensured that the material selected for the study was in fact steel 15B30, allowing the comparison of results with other studies carried out.

In turn, metallography allowed to observe whether the desired microstructures were obtained for the quenching procedure. Figure 1 shows the micrograph of the region in the center of the sample.

Figure 1: metallography of the sample center.



As seen in the figure, the use of polynylpyrolidone without dilution was not effective in quenching the interior of the material. As we can assess, the miscrostructure is formed predominantly by ferrite and perlite, with dispersed carbides [17,18]. Figure 2 shows the metallography corresponding to the sample surface.

Figure 2: metallography of the sample surface.

As in the innermost region of the material, the cooling of the material was not effective for the formation of a martensitic matrix. Therefore, it is evident that the use of PVP under the established working conditions is not a viable alternative for steel hardening. This was because the increase in concentration also promotes an increase in fluid viscosity. In addition, higher viscosities form thicker and more stable vapor layers, causing lower rates of thermal exchange [19].

This same steel, when quenched under the same austenitizing temperature, cooled in a traditional fluid, developed a martensitic matrix with bainite in the matrix [17]. Thus, we verified that the use of 100% PVP does not have sufficient heat removal capacity. This same situation occurred with the 100% PAG, evidencing the need to apply lower concentrations of the fluid to obtain effective results in heat treatment [13]. It is important to note that the application of PVP with concentrations of up to 25% demonstrated efficiency in obtaining martensite in low alloy steels [15]. Finally, it is very likely that changing process conditions can also provide higher cooling rates, but obtaining the desired microstructural matrix is not guaranteed. In particular, the application of agitation in the fluid proves to be important, since it facilitates the breaking of the vapor layer, reducing the first phase of quenching and increasing the cooling [20].

4 CONCLUSIONS

The use of PVP without dilution is not feasible for cooling 15B30 steels in the thermal treatment of quenching.

The microstructure obtained in the heat treatment is characteristic of cooling processes with carbon diffusion, obtained in longer cooling times.

To obtain the desired results, it is necessary that the PVP be diluted in lower concentrations. The optimization of the process conditions, mainly the application of agitation, are viable alternatives to use the fluid in the quenching of 15B30 steels, obtaining better results.

REFERENCES

[1] CANALE, L.C.F.; TOTTEN, G.E.; CANALE, A.C.; **Polímeros de têmpera à base de PAG**, Minerva, p.209-2014, 2006.

[2] MONROE, R.W; BATES, C.E. **Evaluating Quenchants and Facilities for Hardening Steel.** Journal of Heat Treating, v. 3, p. 83-99, 1983.

[3] TOTTEN, G.E. **Steel Heat Treatment Handbook**. 2 ed. Nova Iorque: CRC Press, 2007.

[4] BUCZEK, A.; TELEJKO, T. **Investigation of Heat Transfer Coefficient During Quenching in Various Cooling Agents**. International Journal of Heat and Fluid Flow, v. 44, p. 358-364, 2013.

[5] OLIVEIRA, M.L.; JE RUPPENTHAL, J.E. VERGARA, L.G.L. **Indústria da construção sustentável: uma análise da certificação leed no mercado brasileiro**. Brazilian Journal of Development, v. 6, p. 24942-24950, 2020.

[6] ASM INTERNATIONAL. **ASM Handbook: Heat Treatment**. V.4. 10 ed. Russell Township: ASM International, 1990.

[7] TOTTEN, G.E; TENSI, H.M.; LAINER, K. **Performance of Vegetable Oils as a Cooling Medium in Comparison to a Standard Mineral Oil.** Journal of Materials Engineering and Performance, v. 8, p. 409-416, 1999.

[8] MACKENZIE, D.S. **Selection of Oil Quenchants for Heat Treating Processes.** International Heat Treatment and Surface Engineering, v. 8, p. 8-14, 2014.

[9] MAGEE, C.L.; DAVIES, R.G. **The Volume Expansion Accompanying the F.C.C. to B.C.C. Transformation in Ferrous Alloys**. Acta Metallurgica, V. 20, p. 1031-1043, 1972.

[10] NEVES, F.O. et al. **Influence of Heat Treatment on Residual Stress in Cold-Forged Parts.** Advances in Materials Science and Engineering, v. 2014, p 1-6, 2014.

[11] GRUM, J.; BOZIC, S. **Influence of steel masses and quenchants on mechanical properties of steel.** International Journal of Materials and Product Technology, v. 24, p. 224–240, 2005.

[12] IKKENE, R.; KOUDIL, Z.; MOUZALI, M. **Cooling Characteristic of Polymeric Quenchant: Calculation of HTC and Prediction of Microstructure and Hardness.** Journal of Materials Engineering and Performance, v. 23, p. 3819-3830, 2014.

[13] RAMESH, G.; PRABHU, K.N. **Effect of Polymer Concentration on Wetting and Cooling Performance during Immersion Quenching.** Metallurgical and Materials Transactions B. v. 47, p. 859-881, 2016.

[14] SARKAR, I. et al. **Effect of Polymer Additive on the Cooling Rate of a Hot Steel Plate by Using Water Jet.** Experimental Thermal and Fluid Science, v. 70, p. 105-114, 2016.

[15] VIEIRA, R.V., BIEHL, L.V., MEDEIROS, J.L.B., DA SILVA, A.B., DA SILVA, M.S. **Efeitos da variação da concentração de solução polimérica aquosa a base de PVP na têmpera de aço AISI 4140**. Revista Matéria, v. 24, p. 1-11, 2019.

[16] RESTREPO, H.S. **Propriedades Mecânicas del Acero 15B30**. Revista Universidad EAFIT, v. 124, p. 67-75, 2001.

[17] RESTREPO, H.S.; TOBÓN, D.M. **Resistencia a la Abrasión vs. Resistencia al Impacto del Acero AISI 15B30 Templado y revenido**. Dyna, v. 153, p. 125-133, 2007.

[18] ASM INTERNATIONAL. **ASM Handbook: Metallography and Microstructures**. V.1. 10 ed. Russell Township: ASM International,1990.

[19] LOUAI, A. et al. **Polymer Aqueous Solutions as Quenching Media Polyvinylpyrrolidone.** Journal of Applied Polymer Science, V. 43, p. 2151-2160, 1991.

[20] HERNANDEZ, H.J.V.; MORALES, B.H. **A novel probe design to study wetting front kinematics during forced convective quenching.** Experimental Thermal and Fluid Science, v. 33, p. 797–807, 2009.