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METALLURGICAL ANALYSIS OF CONTROLLED COOLING OF A COMPONENT AFTER HOT FORGING[1]

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Abstract

The purpose of this study is to evaluate the possibility of replace the current normalizing heat treatment of forged pinions through the controlled cooling by taking advantage of the heat from hot forging process. It has been used thermal cycles which would cooled down the pieces right after its hot forged process resulting in proprieties within the specified range lines in the product project, that is, microstructure, hardness and grain size. The research was carried out in the line of production, inside the factory, using a metal box with termal insulation and using a electrical resistance furnace, after this, the metallurgical analysis were made through metallographics and hardness tests. The possibility of using cooling after forging the proposed experimental test in insulated box was ineffective because there was an excessive increase in hardness and an excessive increase in grain size. The results of the tests in the muffle furnace were very significant because it was obtained structure of perlite and ferrite refined, between 7 and 8 ASTM, and within the specified hardness similar to the conventional process of normalization. This results shows that is possible adjust and control controlled colling to replace the conventional normalizing process.

Key words: Hot forging; Controlled Cooling; Normalizing; DIN 16MnCr5.

ANÁLISE METALÚRGICA DO RESFRIAMENTO CONTROLADO DE UM COMPONENTE APÓS FORJAMENTO À QUENTE

Resumo

O objetivo deste estudo é avaliar a possibilidade de substituir o tratamento térmico atual de normalização de pinhões forjados através do resfriamento controlado aproveitando o calor de forjamento à quente do processo. Foram usados ciclos térmicos que resfriassem as peças logo após seu processo de forjamento à quente, resultando em propriedades dentro das especificadas pelo projeto do produto, ou seja, microestrutura, dureza e tamanho de grão. Os ensaios foram realizados na linha de produção, dentro da fábrica, usando uma caixa de metal como isolamento térmico e usando um forno de resistência elétrica, após isso, as análises metalúrgicas foram feitas através de ensaios metalográficos e de dureza. A possibilidade de utilização de resfriamento controlado após forjamento utilizando ensaio experimental em caixa térmica foi ineficaz pois houve um aumento excessivo na dureza e um aumento excessivo no tamanho do grão. Os resultados dos testes utilizando forno mufla foram muito significativos porque foi obtida a estrutura de perlita e ferrita refinadas, entre 7 e 8 ASTM, e dentro da especificação de dureza semelhante à especificada pelo processo convencional de normalização. Os resultados mostram que através do ajuste e controle do resfriamento imediatamente após o forjamento é possível substituir o processo de normalização convencional.

Palavras chave: Forjamento à quente; Resfriamento controlado; Normalização, DIN 16MnC.

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1 INTRODUCTION

With the raise of the forging market components and the increase of the competition among the companies for market's leadership, the plants needs continuum improvement of the involved processes in the manufacture of mechanical components. Currently, the process of thermal treatment is the stage of the productive process of forged that more demand time and also represents a representative cost very for the companies.

The objective of this work is to evaluate the possibility to substitute the current heat treatment of normalization of pinion forged through the controlled cooling using the advantage of the heat of the hot forging process. The implementation of this new process can reduce significantly the production costs and to diminish the period of delivery of the product therefore the process becomes continuous and uses a lesser thermal cycle.

The controlled cooling consists of cooling the material from one high temperature in predetermined way to prevent hardening, cracking, internal defect or to produce desired mechanical or microstructure properties.[1]

In the last years steelmaking had developed its production, having sped up the development of new products and processes, leading the plants to produce large amounts, in lesser time and objectifying the improvement of the supplied product quality. Ahead of such scene, the reduction in the stages of production, through alternative processes, highly is adjusted. As model for this fact, we have the elimination of the stage annealing, through the controlled cooling, after hot or warm forming processes.[2]

During the cooling of hot forged components using microalloyed steel the cooling rate, immediately after the mechanical work, consequently has very significant paper in the final microstructure and in the mechanical properties of the product.[3]

In the search for a bigger flexibility, rapidity and economy in the processes of plastic forming of metals, the substitution heat treatments by controlled cooling of the material immediately after to be hot forming has been proposal. Differently of heat treatments, the controlled cooling in furnace is carried through after hot forging immediately, using to advantage the restrained heat of the material, to guarantee a cooling rate that allows the formation of a desired microstructure. This allows economy of time and energy in relation to the heat treatments providing costs reduction, leading time and, consequently, a bigger flexibility of productive process. In the productive processes that use hot forging operations followed of machining, generally it is necessary that the forged part is cooled to air surrounding and submitted to an intermediate heat treatment operation of normalization in order to promote the formation of a ferrite-perlite microstructure, with hardness specified between 163 and 187 Brinell, of form to improve material machinable.[4]

2 MATERIALS AND METHODS

In the current process, round plated bars of steel DIN 16MnCr5, Table 1, are warm with induction furnaces in maximum temperatures of 1300 ºC and forged in a horizontal press. After the forming these pinions are placed randomly in a container and carried to the plant patio and cooled to the ambient temperature while they wait to be normalized, in this next stage they are austenitizing until the temperature of 910ºC for 3 hours and 30 minutes after cooled with calm air.

Table 1. Chemical composition

	C	Si	Mn	P Max.	S Máx.	Cr
Specify	0,14/0,19	≤0,40	1,00/1,30	0,035	0,035	0,80/1,10
Found	0,15	0,24	1,21	0,019	0,022	0,99

The required specification is Perlite and Ferrite microstructure with grain size of grain between 5 and 8 ASTM and maximum hardness equal to 170 HB.

Before carrying through the experimental tests had been analyzed the metallurgic and mechanical characteristics of raw material (01 sample), as-forged (05 samples randomly taken after cooling inside of the container, of the same lot) and normalized condition (02 samples of different lots).

The hypothesis of using a slow cooling of the parts after the forging was tested in a air-tight system and isolated thermally of the environment with assist it of a metallic box (carbon steel plate with 3 mm thickness, base dimension area of 600 mm x 600 mm with height of 500 mm internally coated in all the 6 sides with a layer of 100 mm of refractory material) the attainment of a next condition the specified one. Diminishing cooling rate it expects to it attainment hardness low values but with the increase of grain size. In Figure 1 the used metallic box in the described experiment is show.

Figure 1. Metal box used for cooling experiment.

The experimental cooling curve was measured right before the hot forging, at ± 1100 °C to determine the heat loss behavior of the part using the metallic box.

Approximately in 12 minutes was reached the temperature of 560 °C, temperature where already had occurred the most significant metallurgic transformations using slow cooling.[1]

For the metal box cooling test the temperatures from cooling had been 1200 °C, 800 °C, 700 °C and 600 °C, with time of confinement of 12 minutes, after, the part was removed of the box and cooled with calm air. The 12 minutes time was kept for the tests for a standardization question.

In the other experimental test a muffle furnace was used for attainment of a heating until the normalization temperature, with heating starting temperature by 700 °C and 600 °C after hot forging process as shows Figure 2. The pinions had been heat right from temperatures at which transformation of austenite to ferrite plus cementite is completed during cooling, i.e., 723 °C - Air_1.[5]

The heating temperatures inside the funace had been from 600 °C and 700 °C, with 15 minutes of soaking time, after the part was removed of the furnace and cooled with calm air. The soaking time was approximate in function to be small mass.

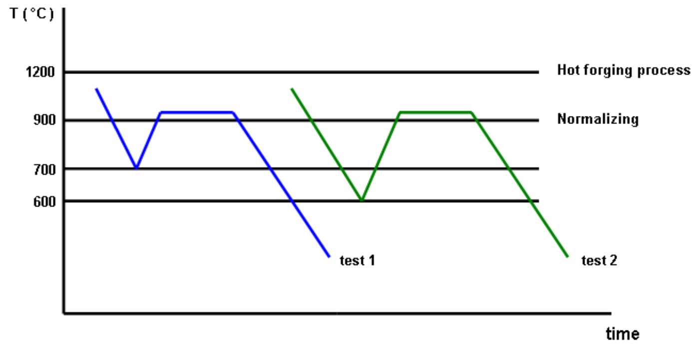

Figure 2. Eschematic graphic of cooling experiment.

On the flowchart, Figure 3, below there is an overview of the tests and the analysis made.

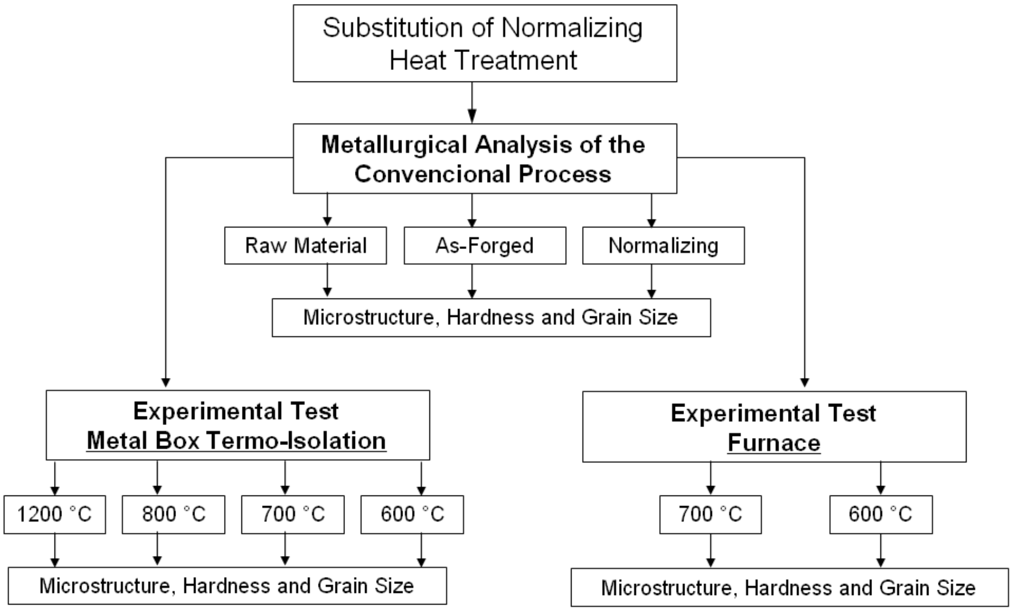

Figure 3. Flowchart of all metallurgical analysis.

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3 RESULTS

All the results are show on the Tables 2, 3, 4, 5 and 6.

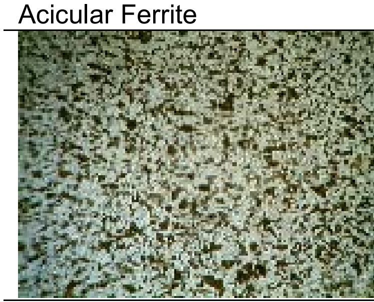
3.1 Raw Material

Table 2. Microstructure and hardness results of the raw material

		
Magnifiction **100x**	**200x**	**400x**
Perlite and Ferrite	7 ASTM	Hardness: 167 HB

3.2 As-Forged

Table 3. Microstructure and hardness results of as-forged

		
Part 1 – Perlite, Ferrite and Acicular Ferrite	6 ASTM	Hardness: 166 HB
		
Part 2 - Perlite and Ferrite	7 ASTM	Hardness: 163 HB
		
Part 3 - Perlite, Ferrite and Acicular Ferrite	5/6 ASTM	Hardness: 180 HB

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	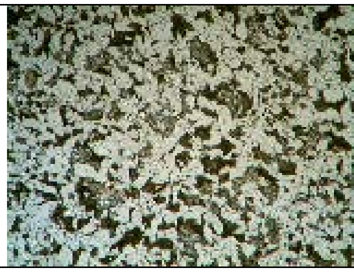	
Part 4 - Perlite, Ferrite and Acicular Ferrite	7 ASTM	Hardness: 165 HB
		
Part 5 - Perlite, Ferrite and Acicular Ferrite	6 ASTM	Hardness: 162 HB
Magnifiction **100x**	**200x**	**400x**

3.3 Normalizing

Table 4. Microstructure and hardness results of the convencional process

		
Part 1 - Perlite and Ferrite	7 ASTM	Hardness: 156 HB
		
Part 2 - Perlite and Ferrite	7 ASTM	Hardness: 159 HB
Magnifiction **100x**	**200x**	**400x**

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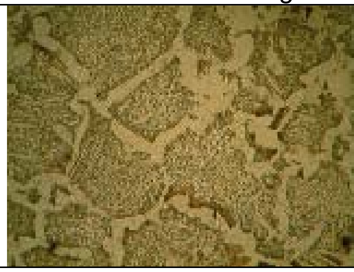
3.4 Cooled in Metal Box

Table 5. Microstructure and hardness results of the cooling metal box test

		
Part 1200°C - Perlite, Ferrite and Acicular Ferrite	1, 2 and 3 ASTM	Hardness: 203 HB
		
Part 800°C - Perlite, Ferrite and Acicular Ferrite	2/3 ASTM	Hardness: 207 HB
		
Part 700°C - Perlite, Ferrite and Acicular Ferrite	5/6 ASTM	Hardness: 196 HB
		
Part 600°C - Perlite, Ferrite and Acicular Ferrite	5/6 ASTM	Hardness: 200 HB
Magnifiction **100x**	**200x**	**400x**

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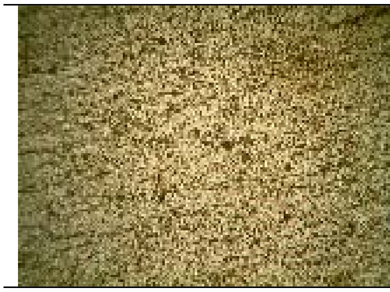
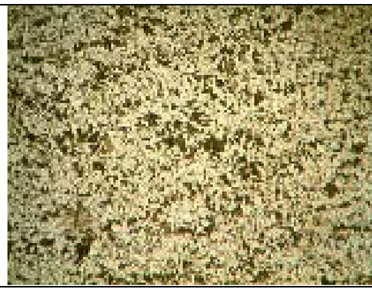
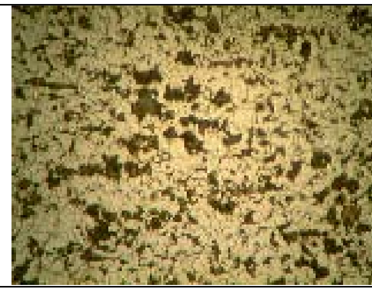
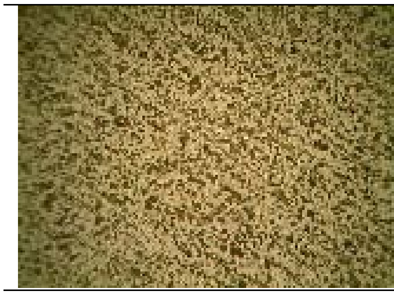
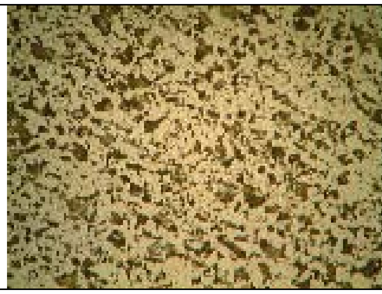
3.5 Controlled Cooled

Table 6. Microstructure and hardness results of furnace test

		
Test 600°C – Perlite and Ferrite	8 ASTM	Hardness: 165 HB
		
Test 700°C – Perlite and Ferrite	7 ASTM	Hardness: 173 HB
Magnifiction **100x**	**200x**	**400x**

4 DISCUSSION

4.1 Raw Material

The microstructure observed was perlite and ferrite refined and homogeneous distributed with hardness of 167HB. Coincidently inside of especification of the final forged product. As a reaction many times initiates in the grain boundaries, a method of controlling the speed of phase transformation is through adjustment of these surfaces. Thus a steel with austenitic refines grains will transforms more quickly than a steel with coarser granulation.[6]

4.2 As-Forged

The microstructure in as-forged condition presented its phases not uniformly distributed (dispersed) and variable among the 5 analyzed parts.[7] Among the 5 evaluated parts, 4 had presented composed microstructure of perlite, ferrite and acicular ferrite. The best observed structural condition was in part 2 (only perlite and ferrite) and the worse condition was found in part 3 therefore presented a bigger ratio of the acicular structure. The grain size had oscillated between 5 and 7 ASTM. The hardness values had been, respectively, 166, 163, 180, 165 and 162 HB, or either, of the point of view of hardness only sample 3 is with a hardness above of the specification. The cause of this higher hardness shoud be because the higher ratio of acicular structure, this was proven through measures of Vickers microhardness in these phases that had presented average value of 215 HV.

4.3 Normalizing

In the conventional process refined perlite and ferrite with grain size of 7 ASTM, and hardness of 156 and 159 HB was gotten. The specification of the normalized product is perlite and ferrite with grain size between 5 and 8 ASTM and maximum hardness of 170 HB.

4.4 Cooled in Metal Box

All the tests made at different confinement temperatures had presented acicular structure with ferritic grain boundary. At the temperatures of 1200 °C and 800°C the grain size was presented coarser, varying between 1 and 3 ASTM. At the temperatures of 700 °C and 600 °C it had a refining of the size of grain, 5 and 6 ASTM and an increase of the ferritic grain boundary thickness. All the 4 different conditions had presented higher hardness that the objectified one of 170 HB, with average hardness of 200 HB, result of the presence of acicular structure.

4.5 Controlled Cooled

According Yamakami[4] is possible to obtain a desire metallurgical condition by controlling the cooling directly after hot forging process.

In the two tested temperatures with the furnace it was gotten structure of perlite and ferrite, however in 700°C had the beginning acicular ferrite appearance. In both the cases obtained a refining of grain, 7 and 8 ASTM. The hardness had been 165 and 173 HB for the temperatures of 600°C and 700°C respectively. The condition of entrance of the part in the furnace at 600°C resulted in the objectified one, taking care of to all the specifications of the product, that is, perlite and ferrite with grain size of 8 ASTM and hardness of 165 HB.

All the experimental tests had been carried through in the production line making possible the best proximity of real results therefore had involved the practical, real and inherent factors of a production line.

5 CONCLUSIONS

The parts must be normalized after the hot forging because exist microstructural and hardness variability decurrent of the cooling in different conditions when the parts are placed in the container. Through the conventional process of normalization this variability is eliminated and guaranteed the specification of the product.

The increase of the hardness of the parts (as-forge part 3 and all thermally the conditions in the experimental tests in isolated metal box) is consequence of the acicular structure presence.

The possibility to use the controlled cooling after the forging considered in the experimental tests whith isolated box thermally for attainment of the specification of the product revealed inefficacious therefore had extreme increase of hardness (in result of the presence of acicular structure) and extreme increase of the grain size.

The results of the experimental tests in muffle furnace had been very significant therefore got structure of refined perlite and ferrite, between 7 and 8 ASTM, and

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hardness in agree with the specifications. In the condition of heating at 600°C until 900°C per 15 minutes presented optimum result in relation the 700°C temperature. In the condition heating from 600ºC a similar result to the conventional process of normalization was gotten which uses 3 hours and 30 minutes of heating from the ambient temperature.

After the repetition of the tests in 600°C, and validation of the reproducibility can through using a continuous furnace next the forging press the attainment of the optimization of the normalization process becoming this continuous heat treatment to the forging process, however using a lesser heating time. These advantages represent drastic reduction of costs, therefore it uses lesser warm up time, and consequently reduction of the period of delivery of the product for the customer.

REFERENCES

1 AMERICAN SOCIETY FOR METALS. Heat Treatment. ASM Internacional, Vol. 14, 1991.
2 MAHL, R. L. Redução da Resistência Mecânica No Aço SAE 10B30 MOD Através do Resfriamento Controlado na Laminação. Trabalho de conclusão do Curso de Engenharia Metalúrgica: UFRGS, 2004.
3 PEIXOTO, N. H. Caracterização Metalúrgica do Aço SAE 1141 Microligado ao Nióbio por Simulação Física. Tese de Doutorado, PPGEM – UFRGS. Porto Alegre, 2003.
4 YAMAKAMI, W. J.; BUTTON, S. T.; GALLEGO, J.; LIMA, C. R. P. de; MATSUMOTO, H. Eliminação de tratamento térmico utilizando resfriamento controlado: Uma proposta para flexibilizar o forjamento a quente. CONGRESSO BRASILEIRO DE ENGENHARIA E CIÊNCIA DOS MATERIAIS, 16, 2004, Porto Alegre - RS. Anais. Porto Alegre: CBECIMAT, 2004. (CDROM).
5 TOTTEN, George. E.; Steel Heat Treatment - Metallurgy and Technologies. Second Edition; 2007.
6 KRAUSS, G., Steels - Heat Treatment and Processing Principles, ASM International, Materials Park, OH, 1990.
7 FORGING INDUSTRY ASSOCIATION. Forging Handbook. ASM Internacional, 1985.