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Analysis and Experience using Process Modeling for Developing New and Corrective Heat Treat Schedules for Deep Case Carburizing

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Abstract

Achieving deep carburized cases in large parts, i.e. depths of 2mm or more, can often be problematic. Requiring long diffusion times at temperature, unanticipated furnace power fluctuations, changes in gas supply, inaccurate probe function, and/or atmosphere changes may result in insufficient case depth. Rising energy costs make methods for calculating efficient carburization schedules more critical. Methods used for shallow case applications may not be suitable for determining deep case schedules. The same holds for changes in alloy content, where shallow case prediction errors may be inconsequential, but highly influential for deep cases. This presentation will show new methods for calculating deep case carburizing schedules, as well as methods where corrective carburization is required when insufficient case depths are initially achieved. The computational modeling technique presented is validated against experience carburizing large AISI 3310 components for the mining industry. Practical utility of such modeling for deep case carburizing applications is presented.

Introduction

Deep case carburizing of steel presents several challenges. Long diffusion times are necessary to achieve the required case depth. Whereas overall depth of the case may not be particularly sensitive to surface carbon potential fluctuations, these same variations can lead to surface grain boundary carbides. Developing metallurgically sound and efficient carburization cycles for deep cases has long been a challenge for heat treaters and metallurgical engineers. Standard carbon diffusion equations and calculation methods become increasing more challenging when deep cases with multiple boost and diffuse cycles are required. They become even more challenging when attempting to characterize diffusion behaviour in previously carburized steels that may require a second, salvage carburization process. In this case, a pre-existing gradient adds complexity to the diffusion response, which is best addressed through computational methods. This paper demonstrates the utility of such methods in determining deep case carburization response. A case study showing application of this method to an insufficiently carburized gear requiring a salvage carburization cycle is presented.

Case Study Component, Processes and Carburizing Model

Case Study Component

As an example of a component requiring deep case carburizing, a 3310 steel gear for a typical mining application was chosen to demonstrate the utility of carburizing process modeling to illustrate important process response. AISI 3310 steel chemistry is given in Table 1. AISI 3310 is a chromium-nickel carburizing steel having exceptionally high hardenability. It is suited for heavy section parts requiring high surface hardness and a strong and tough core.

Table 1.AISI 3310 Nominal Chemistry

C	Mn	P	S	Si	Ni	Cr	Mo
0.08 – 0.13	0.45 – 0.60	0.025	0.025	0.20 – 0.35	3.25 – 3.75	1.40 – 1.75	3.25 – 3.75

The part chosen for this case study is a carburized 3310 bull gear, 10.95” (274mm) in diameter, with an effective case depth of 0.068” – 0.088” (1.73mm – 2.24mm), see Figure 1.

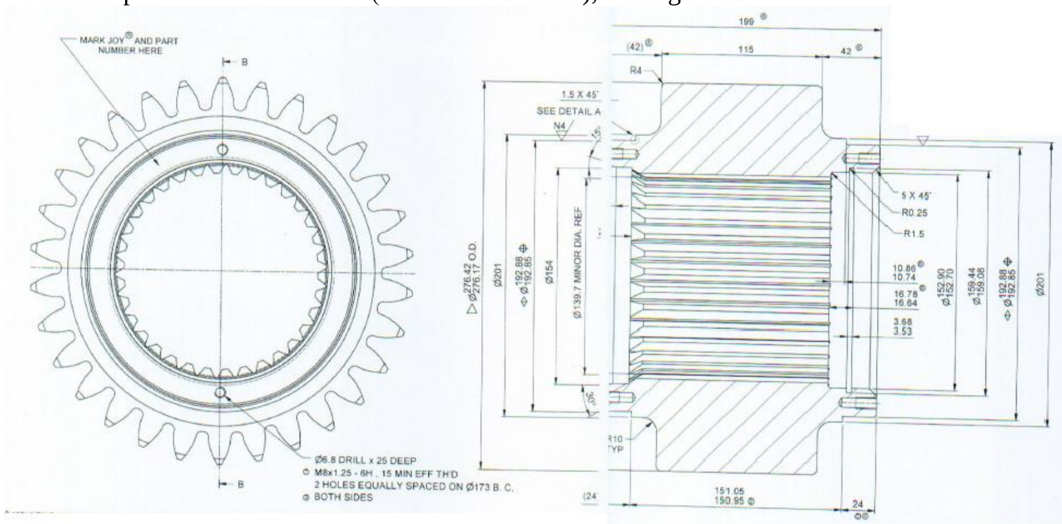

Figure 1: AISI 3310 demonstration bull gear requiring 0.068” – 0.088” effective carburized case.

For illustrative purposes of this case study, an example deep case carburizing cycle for this gear is given in Table 2. This is an actual commercial cycle which had been historically applied for this gear.

Table 2. AISI 3310 Nominal Chemistry

STEP	TEMP (ºF)	CARB POTENTAL	TIME (hours)
Preheat	1500ºF	0.30%	2 hours
Carbon Boost	1700ºF	0.90%	12 hours
Diffuse	1700ºF	0.80%	22 hours
Reduce	1500ºF	0.70%	4 hours

Modeling Approach to Process Design and Reprocess Schedule Development

Computational modeling of a carburizing cycle enables quantifying the simultaneous transient response of the shifting internal carbon gradient and the changing surface carbon potential. In a rework scenario, it is important to be able to accurately predict the carbon profile resulting from multiple diffusion steps.

The modeling approach for the large case calculations used the mass diffusion capabilities of the commercial DANTE® heat treatment prediction software. DANTE® is a finite element based software used for simulating carburization, quench hardening, and tempering of steel parts. A simple one dimensional section model is all that is required for these carburization calculations. A cross sectional thickness equivalent to the gear section centerline – surface dimension is all that is required, which for the subject gear is 0.3” (7.62mm). A simple mesh is then built for this section, allowing DANTE to calculate simultaneous thermal and carbon diffusion response for the process under consideration.

For this case, the effective case depth was defined as the depth where the minimum hardness is HRC 50. For AISI 3310 in a carburized and quenched condition, this is equivalent to a depth where the local carbon level is 0.40%. The effective case depth for the cycle defined in Table 2 is predicted to be 0.076” (1.93mm). Figure 2 shows a plot of the predicted carbon profile, including notation of the effective case depth.

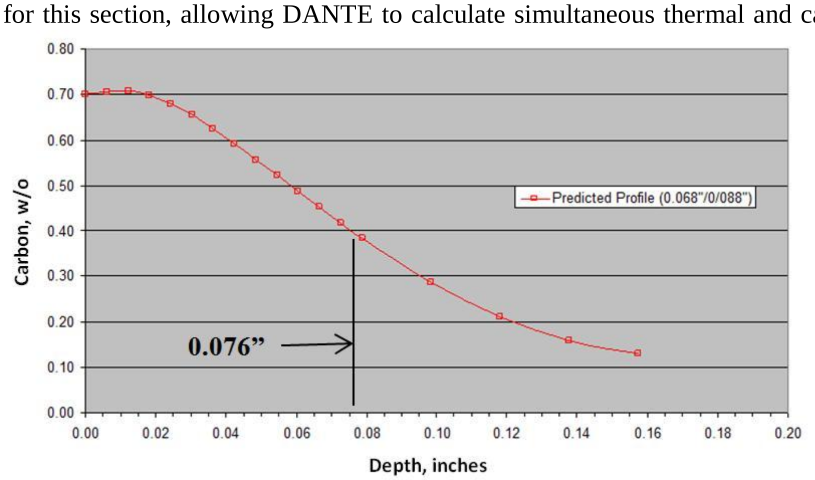

Figure 2: Predicted carbon profile for the 3310 gear using carburization cycle shown in Table 2.

Deep Case Carburizing Response Prediction for Process with Malfunctioning Carbon Probe

Reported Case Depth from Insufficiently Carburized 3310

After processing, the subject gear showed an insufficient carburized case depth based on measured hardness profile. The root cause of the problem was found to be a defective carbon probe, which resulted in the reduction of the actual applied surface carbon potential by 0.10%-0.15%. The effective case depth was measured to be 0.055" (1.40mm). Assuming the base process as defined in Table 2 and also that the carbon probe malfunction resulted in an under application of the proper carbon potential setting, a series of models were then run to determine the actual carbon potential applied on the part, as well as a prediction of the actual carbon gradient.

Figure 3 shows the predicted carbon gradient matching the effective case depth measurement for the gear, and Table 3 defines the process showing the adjusted "real" carbon potential experienced ion the part surface which likely produced the under carburization result.

Table 3. AISI 3310 Nominal Chemistry

STEP	TEMP (ºF)	CARB POTENTAL	TIME (hours)
Preheat	1500ºF	0.18%	2 hours
Carbon Boost	1700ºF	0.78%	12 hours
Diffuse	1700ºF	0.68%	22 hours
Reduce	1500ºF	0.58%	4 hours

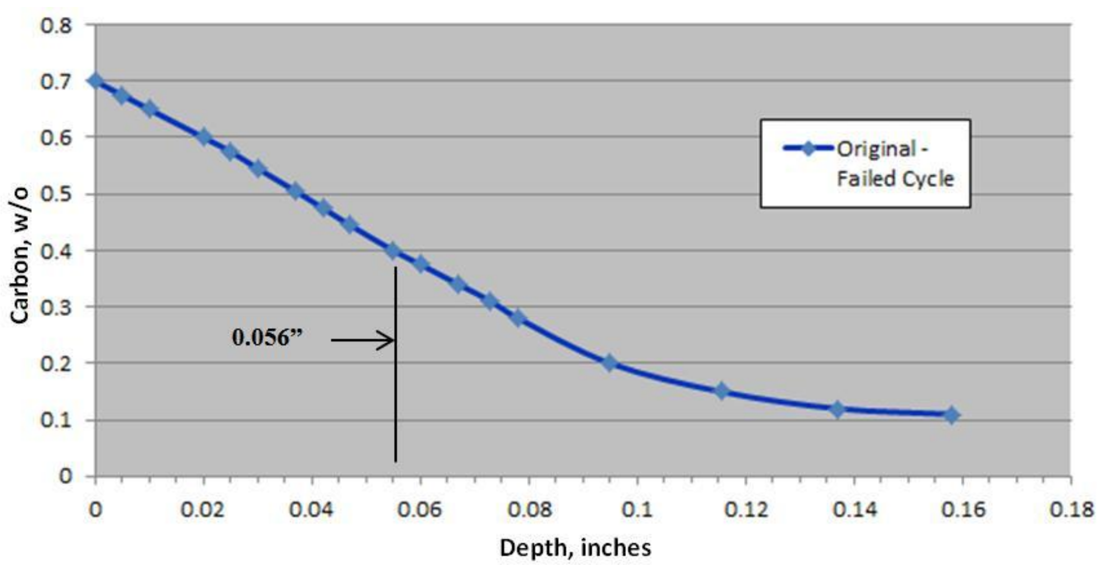

Figure 3: Predicted carbon profile and effect case depth using ineffective cycle shown in Table 3.

This profile is important for use in establishing a subsequent salvage heat treatment necessary to recarburize the part and achieve the required deep case of 0.068" – 0.088".

Reprocessed Gear - Case Depth Prediction

In actual industrial case study, the carbon probe malfunction was corrected such that proper control of physical carbon potential in the carburizing furnace was restored. With the knowledge that no artificial adjustments in carbon potential were required for the subsequent models, the pre-carburized section was used as the foundation for additional carburization model runs to determine a salvage carburization cycle to achieve the required 0.068" – 0.088" case.

Again using the DANTE carburization model, a salvage cycle was determined in which an adjustment to shorter boost, diffuse and "reduce" steps; and maintenance of the same preheat time. Temperatures were not adjusted. The determined salvage carburization process is given in Table 4.

Table 4. Salvage carburization cycle used in reprocessing gear subjected to prior cycle given in Table 3.

STEP	TEMP (ºF)	CARB POTENTAL	TIME (hours)
Preheat	1500ºF	0.30%	2 hours
Carbon Boost	1700ºF	0.90%	6 hours
Diffuse	1700ºF	0.80%	14 hours
Reduce	1500ºF	0.70%	3 hours

The resulting predicted carbon profile is shown in Figure 4, along with predicted profile from the incoming case of insufficient carburization. The salvage carburization cycle produced an effective case depth of 0.077" (1.96mm).

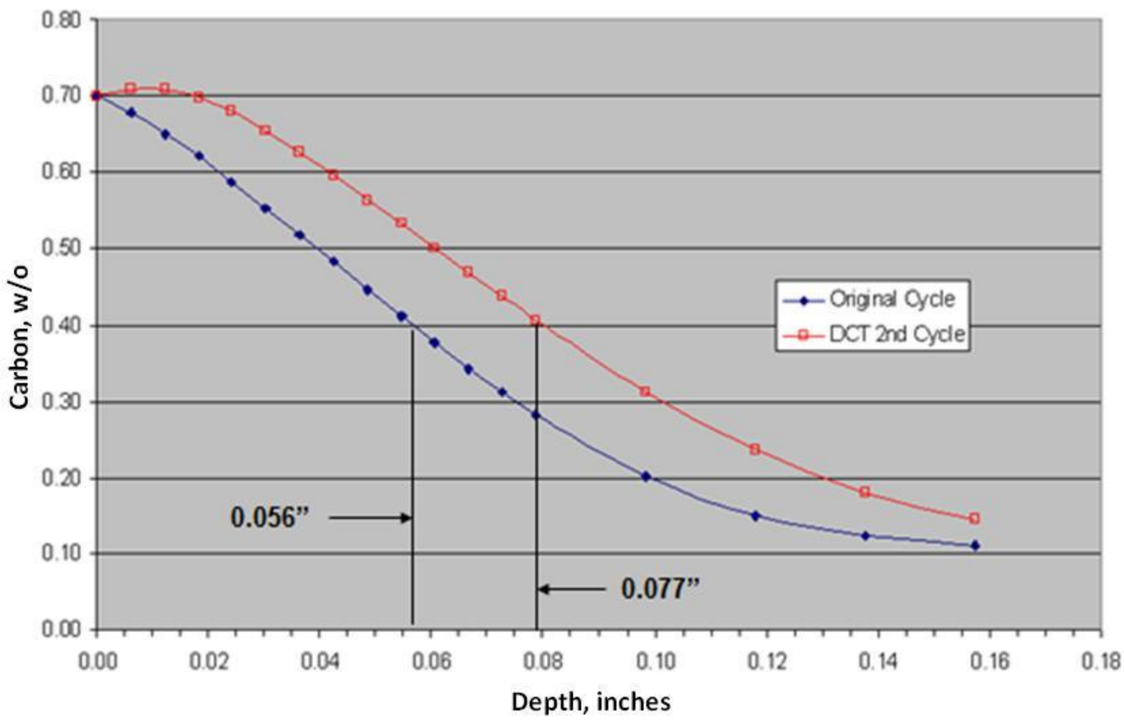

Figure 4: Comparison of predicted carbon profiles for originally insufficiently carburized gear, and same gear subsequently processed using the salvage cycle given in Table 4.

Reprocessing of the gear using the cycle shown in Table 4 produced a 0.80" case depth, which was within specification and reasonably close to the predicted 0.077" depth from the DANTE model.

Summary and Conclusions

Use of a novel computational modelling technique has allowed for characterization of carbon mass diffusion transients during deep case carburizing. The technique has been successfully demonstrated for the case of a 3310 alloy steel gear, in which the primary carburization process resulted in an insufficient case depth. Characterizing the lowered carbon potential allowed for establishing a new baseline carbon profile, from which a new carburization process could be established to achieve the required deep case. The conference presentation will highlight additional application examples and method utility.