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Technical article

Neukirchen-Vluyn (Germany), 7 October 2021

Improved cooling rates in fluidized bed systems

Excellent alternative to salt bath and other heat treatment technologies

During the past few decades, the fluidized bed technology in terms of quality has not lost any of its importance for heat treatment applications and has even become indispensable in some application niches due to its special properties.

Functioning principle of fluidized bed heat treatment system

The functioning principle (figure1) of the fluidized bed heat treatment systems from Schwing Technologies is based on the patented Schwing fluidized bed technology, where fine-grain aluminum oxide is fluidized with air or inert gas in a process chamber. The fluidized bed thus generated conducts heat extremely well and because of its mass possesses an enormous heat capacity.

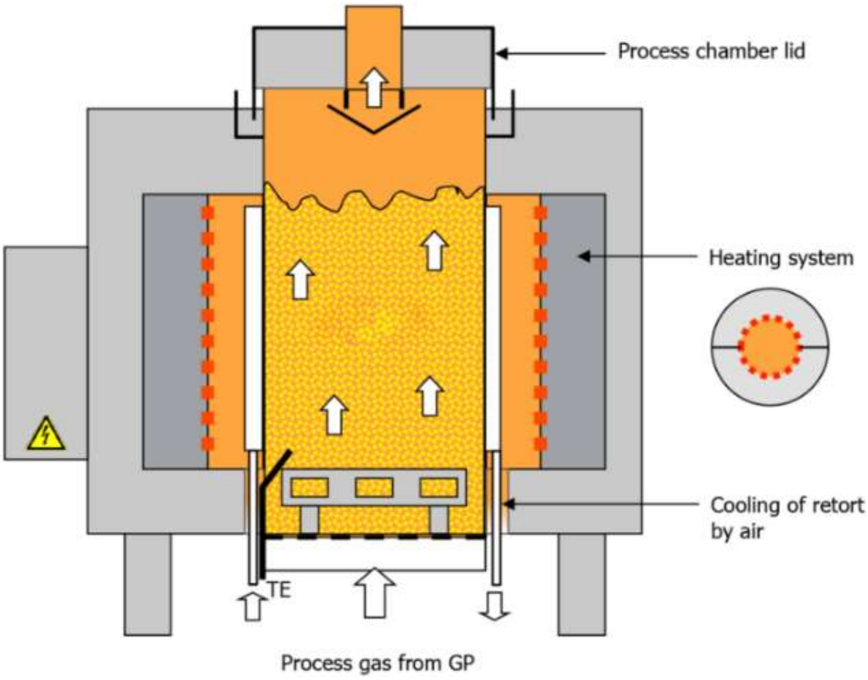

Figure 1: functioning principle of the fluidized bed heat treatment system
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Schwing Technologies heat treatment systems are heated indirectly via electric heaters or gas burners and can be used over a large temperature range from room temperature to 1050 °C with top precision. Metal tools or components can be easily immersed in the fluidized bed, and in the shortest amount of time they can be

- preheated,
- annealed,
- nitrided,
- nitrocarburized,
- tempered
- quenched or
- quenched and tempered with the desired atmosphere and temperature.

Advantages of fluidized bed technology
Interruptions, change-overs or changes of the treatment process and the atmosphere, for example, from thermo-chemical to inert, are possible at any time and within only two to three minutes. The great temperature accuracy of the heat treatment systems from Schwing Technologies during soaking, dwelling and particularly also during heating-up and quenching ensures the non-warping treatment of the batches introduced. Additionally the excellent temperature uniformity is keeping stress in the treated parts at a very minimum which addresses the major disadvantages of liquid quench media and high pressure gas quench system. The quick and uniform heating of the system makes stand-by heating obsolete. The facilities operate completely without waste and upon request they are equipped with a flare unit.

Optimization of the cooling effect in the fluidized bed
As in many other technologies, there is also sometimes a need for optimization in special application areas of fluidized bed heat treatment. One requirement that came from the market was to increase the cooling rates. Among other things, alternatives to austempering in salt bath were sought as well as alternatives to liquid quenching media such as oil or polymer for advanced manufactured metal parts. The main aspects were environmental compatibility and the reduction or avoidance of cleaning post-treatments.

R&D project
The optimization of the cooling effect in fluidized bed was carried out as part of an R&D project of Schwing Technologies and PEER Energy together with the Center of Heat Treat Exellence at the Worcester Polytechnic Institute (WPI) in Worcester, MA in the US with focus on austempering. Due to the required comparability, standardized methods and samples were used. Several preliminary tests for probing the fluidization gases and bath media and all heat treatment trials were performed at the technical centre of Schwing Technologies. The metallographic examinations and material tests were carried out by WPI. This paper essentially concentrates on the third test series at Schwing Technologies for AISI 5160 where the optimization goal was achieved.

First of all, the current status of cooling effect of common fluidized bath systems had to be determined in comparison with other technologies and media. Standard parameters for the equipment, usual fluidization gases (air and nitrogen) and a common aluminum oxide for heat treatment applications were therefore chosen as starting point.

Austempering is a heat treatment process based on the isothermal transformation of austenite to bainite, which forms in the temperature range between pearlite and martensite. To form the bainite, the cooling rate needs to be fast enough to avoid the formation of pearlite at higher temperature as shown in Figure 2.

Then two austempering trials were conducted on AISI 5160 using fluidized bed with different fluidization gases and bath media. The first trial was performed with Al2O3 and the 2nd with a so called B4Q as bath medium. Both trials didn’t make the full bainite due to the slow cooling rates. With a new bath medium, called **G4Q**, and a special fluidization gas, the cooling rates were significantly better than the cooling rates with Al2O3 and standard gases especially in the temperature range between 500 °C and 800 °C which can be seen in figure 2. Therefore, we decided to conduct the third austempering trial using the new fluidized bed bath medium **G4Q**.

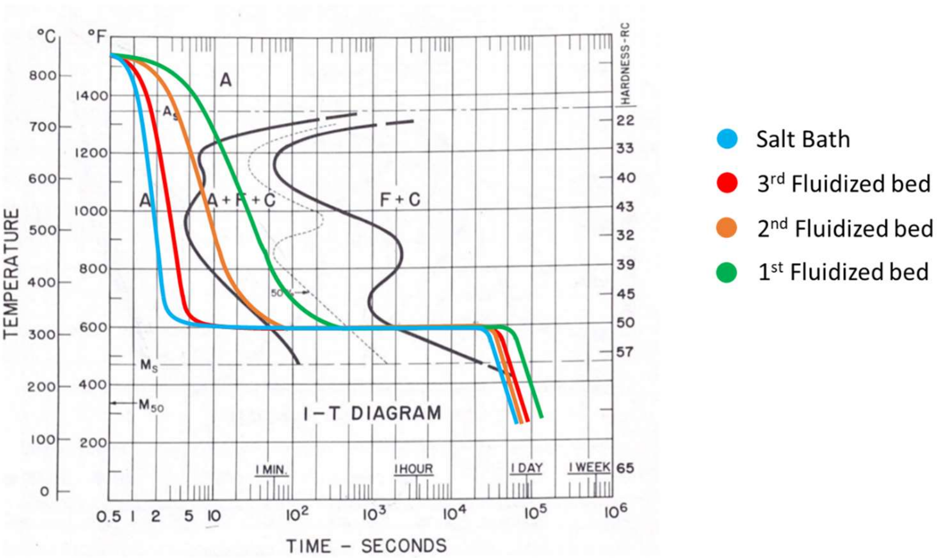

Figure 2: Cooling rates under different conditions in a fluidized bed compared to salt bath
Photo credit: SCHWING Technologies
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The samples were austenitized in a fluidized bed furnace at 850 °C for 30 mins, then austempered in another fluidized bed furnace at 315 °C (600 °F) for 1, 2, 5, 30, and 90 mins, respectively, taken out from the furnace and cooled in air to room temperature. These samples, prepared by WPI, are disks with 1.125” diameter and 0.5” thickness like shown in Figure 3. The austempered samples were shipped back to WPI for characterization including Rockwell hardness measurement, Vickers microhardness line scan, XRD analysis, Optical, and SEM microstructure analysis.

Figure 3: Typical sample used for the austempering trials compared to a US quarter Dollar coin
Photo credit: SCHWING Technologies
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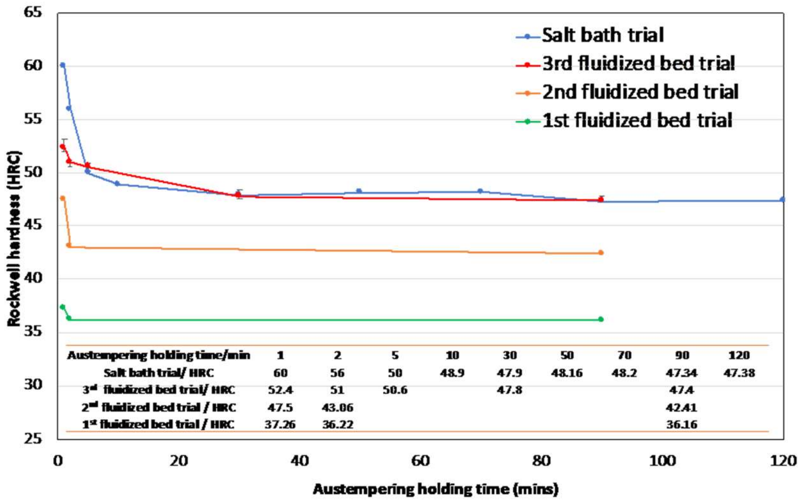
Figure 4 shows the Rockwell hardness of the austempered samples from the 3rd fluidized bed trial, which are compared with the Rockwell hardness of samples austempered in salt bath at same temperature. It can be seen that the hardness data are very close for 30 mins and 90 mins austempering holding time samples. The hardness of austempered samples from 1st and 2nd fluidized bed austempering trials are also shown in this figure. It can be seen that the hardness of 90 mins austempering holding time samples from both 1st and 2nd fluidized austempering trials are lower than the hardness of the sample from the 3rd trial with same austempering holding time.



Austempering holding time/min	1	2	5	10	30	50	70	90	120
Salt bath trial/ HRC	60	56	50	48.9	47.9	48.16	48.2	47.34	47.38
3rd fluidized bed trial/ HRC	52.4	51	50.6		47.8			47.4	
2nd fluidized bed trial / HRC	47.5	43.06						42.41	
1st fluidized bed trial / HRC	37.26	36.22						36.16	

Figure 4: Rockwell hardness comparison of salt bath and fluidized bed austempered samples
Photo credit: SCHWING Technologies
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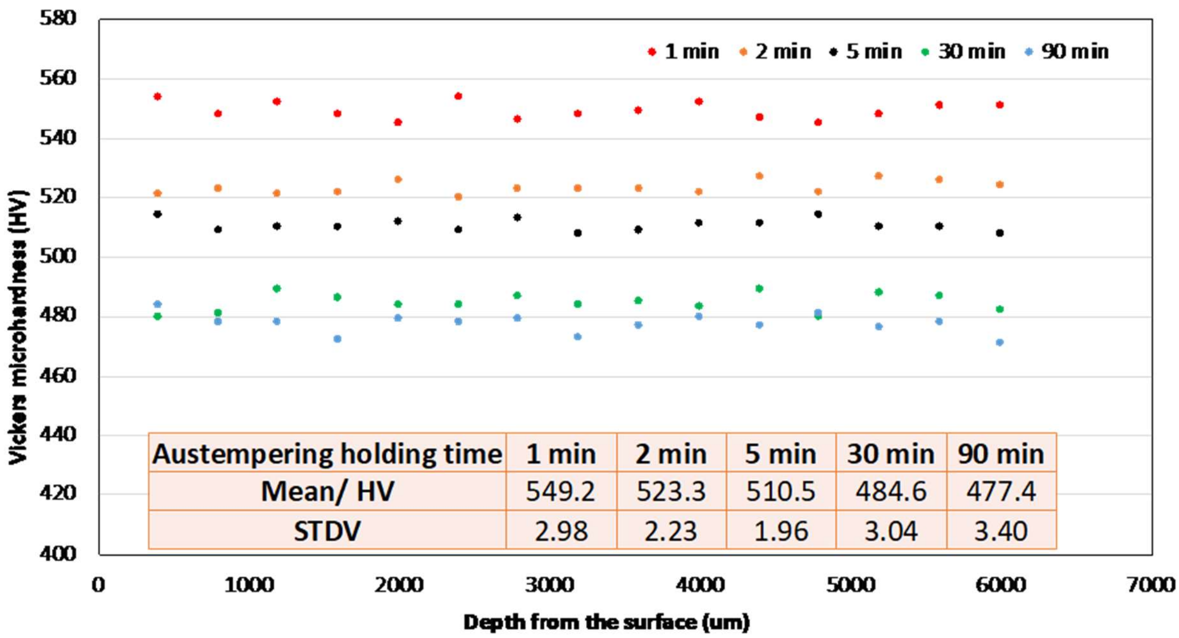
The samples were cut, mounted, and polished for the Vickers microhardness measurements by a Wilson VH3300 (0.5kgf). The Vickers microhardness line scan was conducted on the cross section of these samples from surface to the core. The results are shown in figure 5 with calculated average microhardness and standard deviation. It can be seen that the microhardness is uniform in each sample. The Vickers microhardness decreases with the austempering time increasing, which is in good agreement with the Rockwell hardness measurement results.



Austempering holding time	1 min	2 min	5 min	30 min	90 min
Mean/ HV	549.2	523.3	510.5	484.6	477.4
STDV	2.98	2.23	1.96	3.04	3.40

Figure 5: Vickers microhardness line scan of the samples from 3rd fluidized bed austempering trial with G4Q bath medium
Photo credit: SCHWING Technologies
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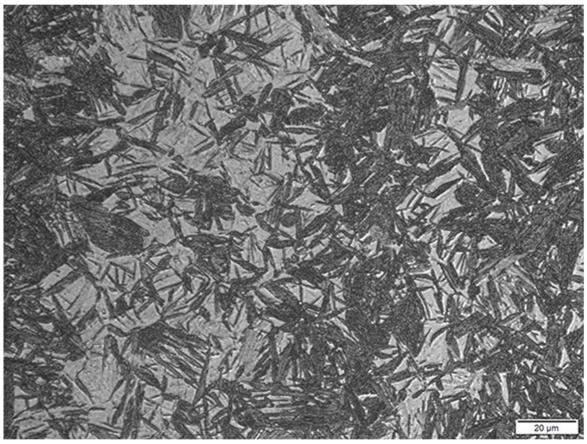
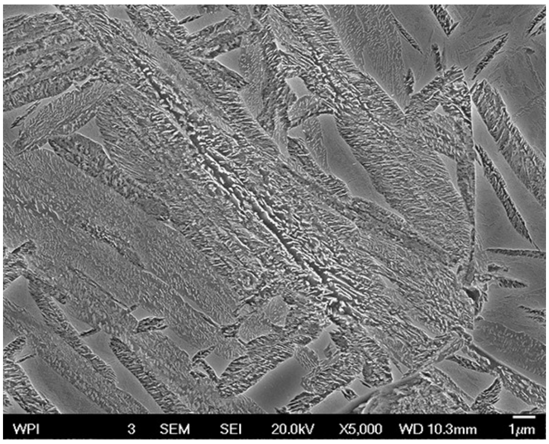
The samples were cut, mounted, polished, and etched by 4 vol.% Nital for the microstructure analysis on the sample cross section by optical and scanning electron microscope (SEM). The optical and SEM micrographs are shown in Figure 6 with optical ones on the left side and SEM ones on the right side. It can be seen that the bainite percentage increases with the austempering holding time increasing. The microstructure of sample with 30 mins austempering holding time (6 (d)) is similar to the microstructure of sample with 90 mins austempering holding time (Figure 6 (e)), which shows the formation of the full bainite.





(a)
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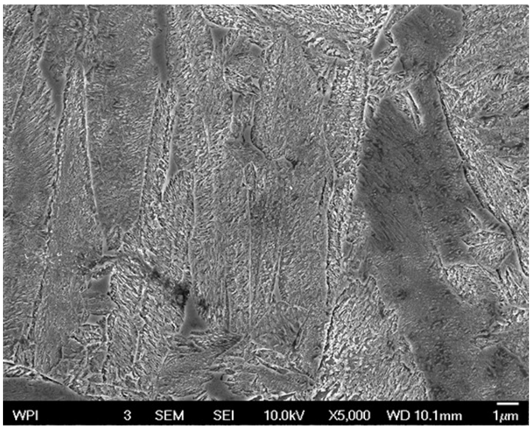

(b)
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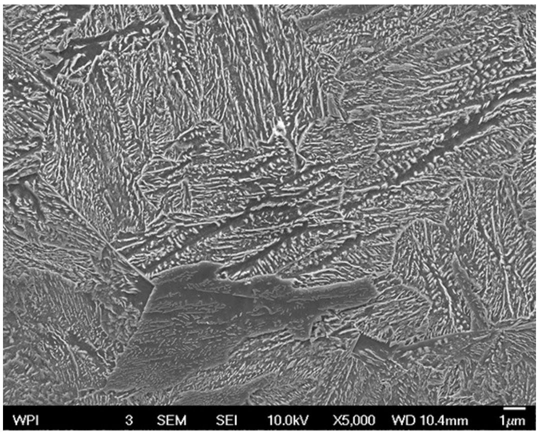

(c)
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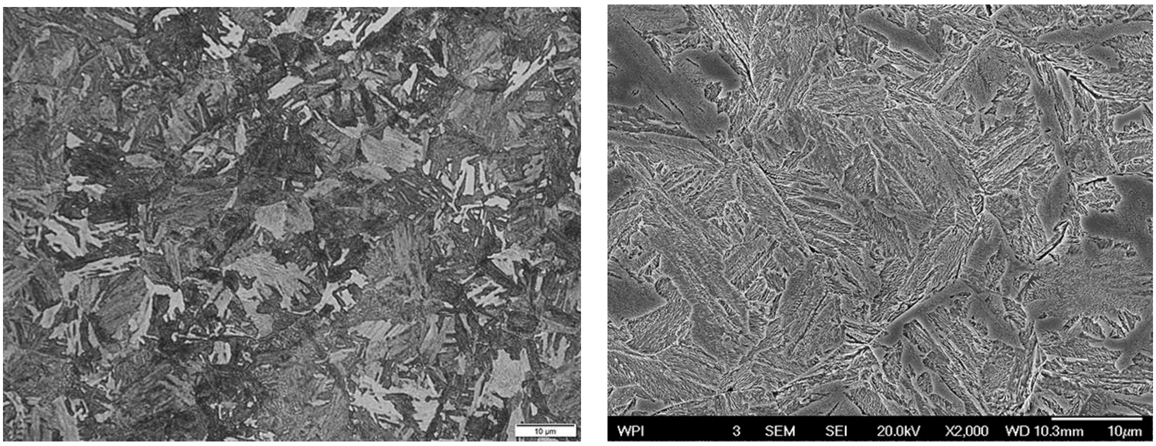

(d)
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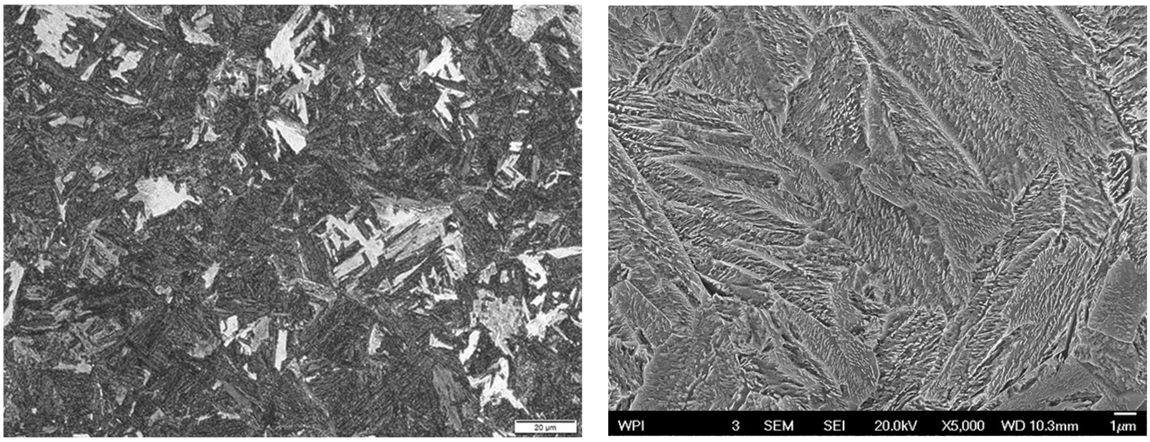
Download: https://drive.google.com/file/d/1eCbHfMlQhazX8p1MTEHgUYOuab_qe6rh/view?usp=sharing



(e)
Figure 6: Optical and SEM micrographs of (a) 1 min (b) 2 mins (c) 5 mins (d) 30 mins (e) 90 mins austempered samples from 3rd fluidized bed trial on cross section (optical micrograph is on the left, SEM micrograph is on the right)
Photo credit: SCHWING Technologies
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The XRD analysis were also carried out on these as-polished austempered samples and the XRD patterns are shown in figure 7. Both bcc (α) and fcc (γ) are identified for the austempered samples with 1, 2, and 5 mins austempering holding time, while only bcc (α) was identified for the sample with 30 and 90 mins austempering holding time. The fcc is retained austenite, the bcc is bainitic ferrite plus martensite in these samples. Therefore, the XRD analysis shows that the full bainite forms in the samples with 30 and 90 mins austempering holding time, which is in good agreement with the hardness measurement and microstructure analysis.

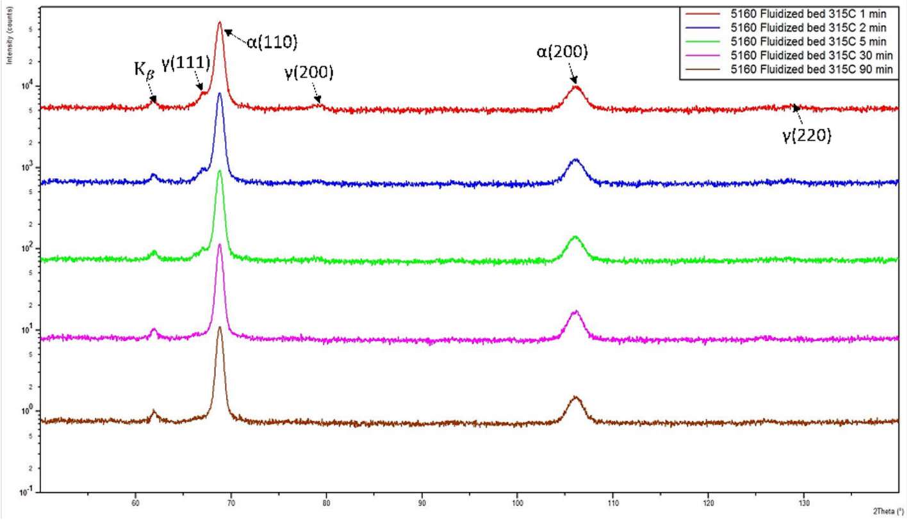

Figure 7: XRD patterns for 1 min (red), 2 mins (blue), 5 mins (green), 30 mins (purple), and 90 mins (brown) austempered samples from 3rd fluidized bed trial with G4Q
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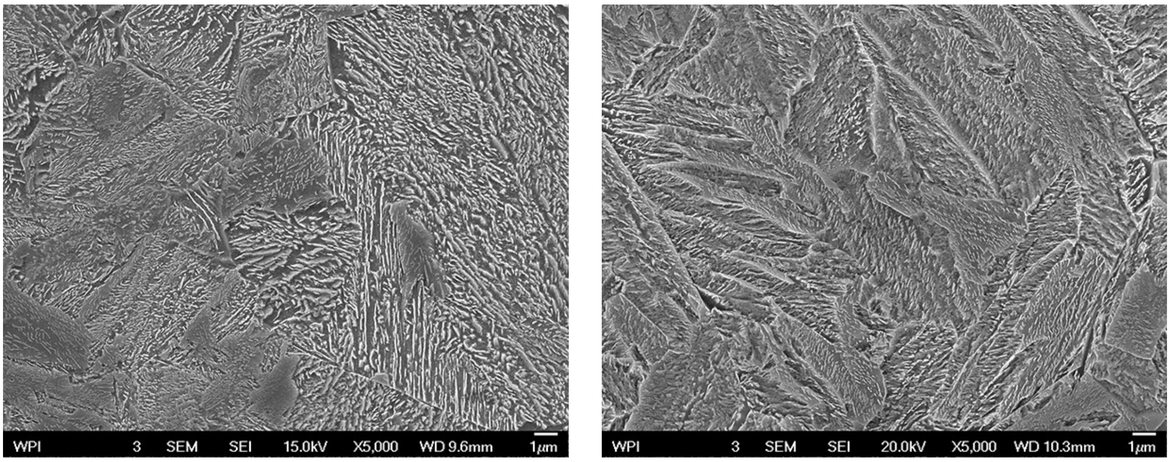
The SEM micrographs of the samples with 90 mins austempering holding time from 2nd and 3rd fluidized bed austempering trial are compared in Figure 8. With high magnification the pearlite can be seen in the sample from the 2nd trial (Figure 8 (a)) while the full bainite forms in the sample from the 3rd trial (Figure 8 (b)).



(a) (b)

Figure 8: SEM micrographs of the samples from (a) 2nd (b) 3rd fluidized bed austempering trial with 90 mins austempering holding time
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Conclusion
The trials have shown that with optimized parameters in a fluidized bed system, which are mainly a special gas and the new bath medium **G4Q**, almost the same cooling rates can be achieved as in a salt bath. The required cooling effect for 100% austempering of the AISI 5160 was fully achieved. This could be proven by metallographic investigations and mechanical material testing.

The fluidized bed systems of Schwing Technologies now offer an excellent alternative to salt bath for this application. For many other conventional applications as well as for innovative processes such as the additive manufacturing of metal parts, this fluidized bed systems offer a very good alternative or even the best fitting solution for cooling and quenching. It comes with all advantages of salt bath, but without its negative environmental impacts. At the same time it can beat any high pressure gas quench process with respect to temperature uniformity during the actual quenching process. As a result the treated parts can uniformly transform and thus keeping stresses at a minimum.

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About Schwing Technologies

Schwing Technologies has been operating for over 50 years and is the worldwide technological leader for high-temperature systems for thermal cleaning, thermo-chemical finishing and heat treatment of metal parts and tools. Managing directors are Ewald Schwing, Thomas Schwing and Alfred Schillert. The owner-managed company designs, manufactures, and operates systems at its headquarters in Neukirchen-Vluyn in Germany's Lower Rhine region. Built upon the achievements of German engineering, the medium-sized business is one of the world's best-known specialists in the removal of plastics. Among Schwing’s approximately 3,000 international clients are companies from the plastics and fiber industries, as well as from the chemicals and automobile sectors. For every cleaning need, the company with its approximately 100 employees offers the most economically, ecologically and qualitatively best technology and cleaning solution. Schwing is also a reliable service partner for contract cleaning by processing more than 250,000 tools and parts each year to the highest environmental and qualitative standards. Founded in 1969, the company celebrates its 50th anniversary in 2019 and opened Schwing Technologies North America Inc., a new sales company in the USA, in that year.

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