Vibratory Stress Relief ELFORSK

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Oct. 2017

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❖ Outline

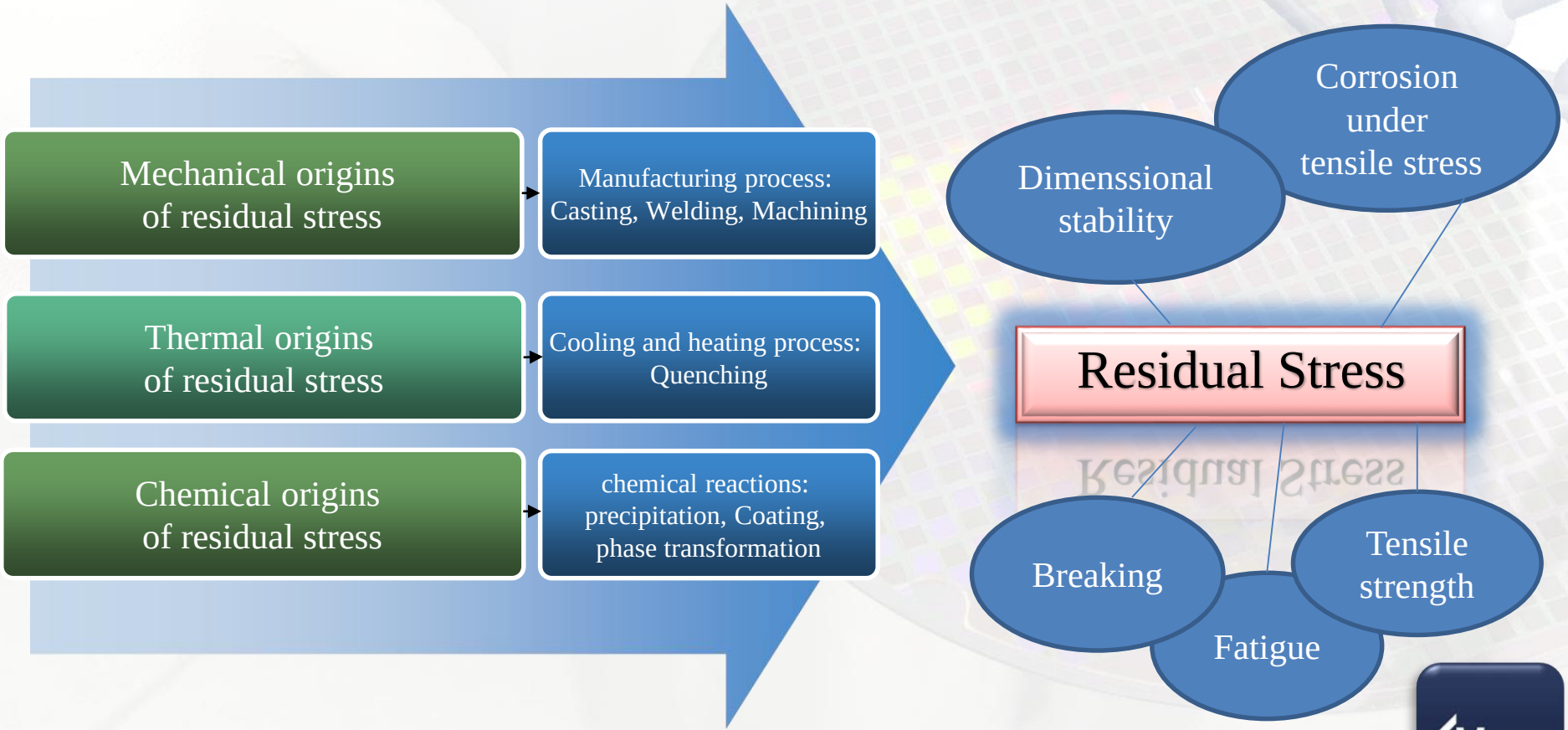
- ✓ Purpose with the ELFORSK project WP4
- ✓ Definition of Residual Stresses in a Microstructural Perspective
- ✓ Techniques for stress relieving, TSR and VSR
- ✓ Techniques for microstructural characterization and analysis
- ✓ Tests and results
- ✓ Summary

❖ Goals

- ✓ To research and document properties of materials before and after stress relieving, using Vibratory Stress Relief (VSR) and Thermal Stress Relief (TSR).
- ✓ To evaluate the changes in material properties before and after stress relieving.
- ✓ To document savings in energy consumption when using VSR instead of TSR
- ✓ To document how the treatment alters the state of stress in the specimens compared to the references.

❖ Definition of Residual Stresses in a Microstructural Perspective

Residual stresses can be defined as the stresses that remain within a material after manufacturing and material processing in the absence of external forces or thermal gradients. They can also be produced by service loading, leading to inhomogeneous plastic deformation in the part or specimen.



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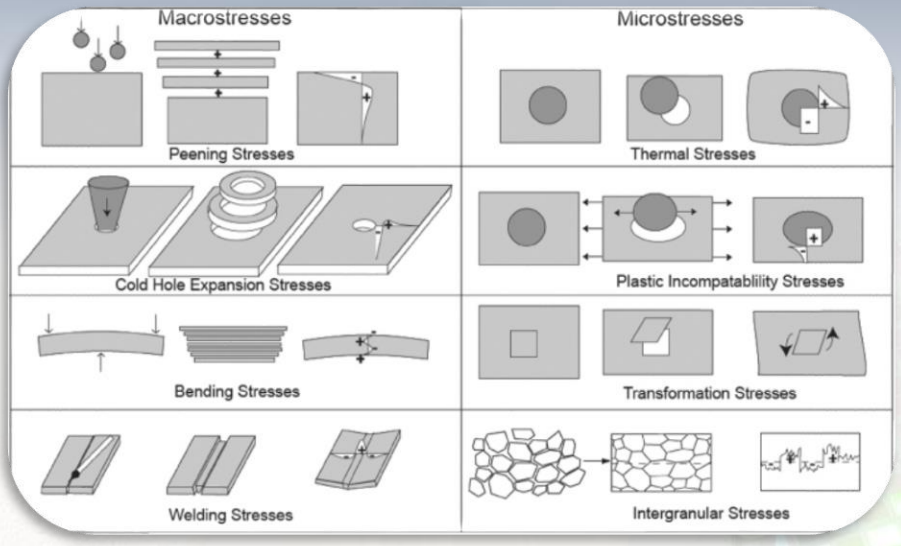
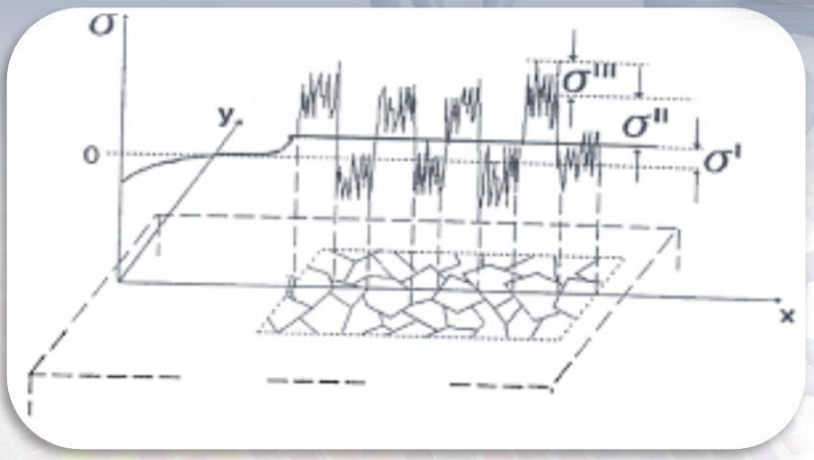
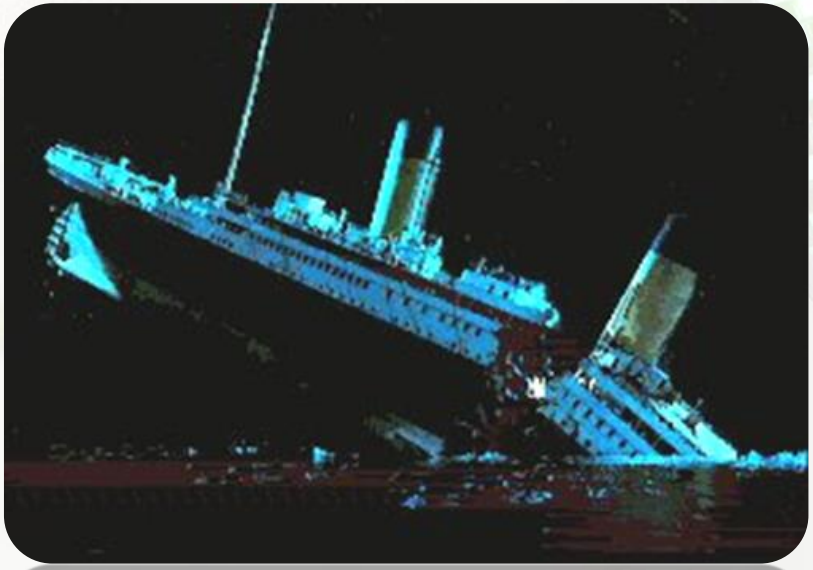
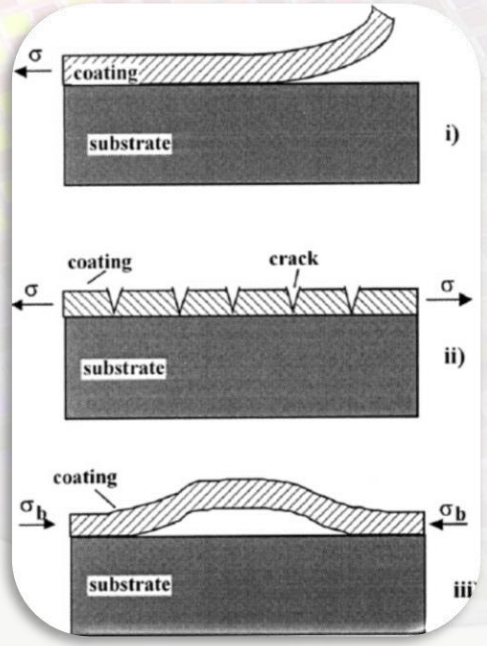
❖ Definition of Residual Stresses in a Microstructural Perspective









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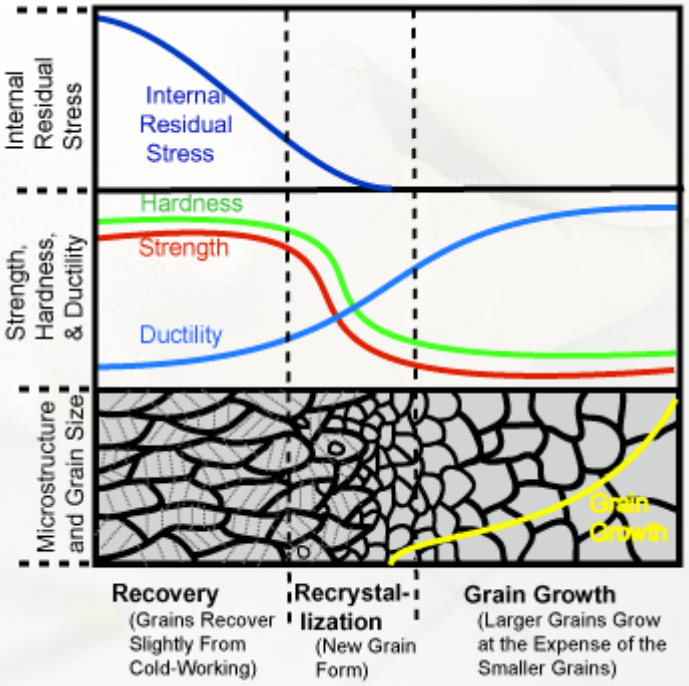
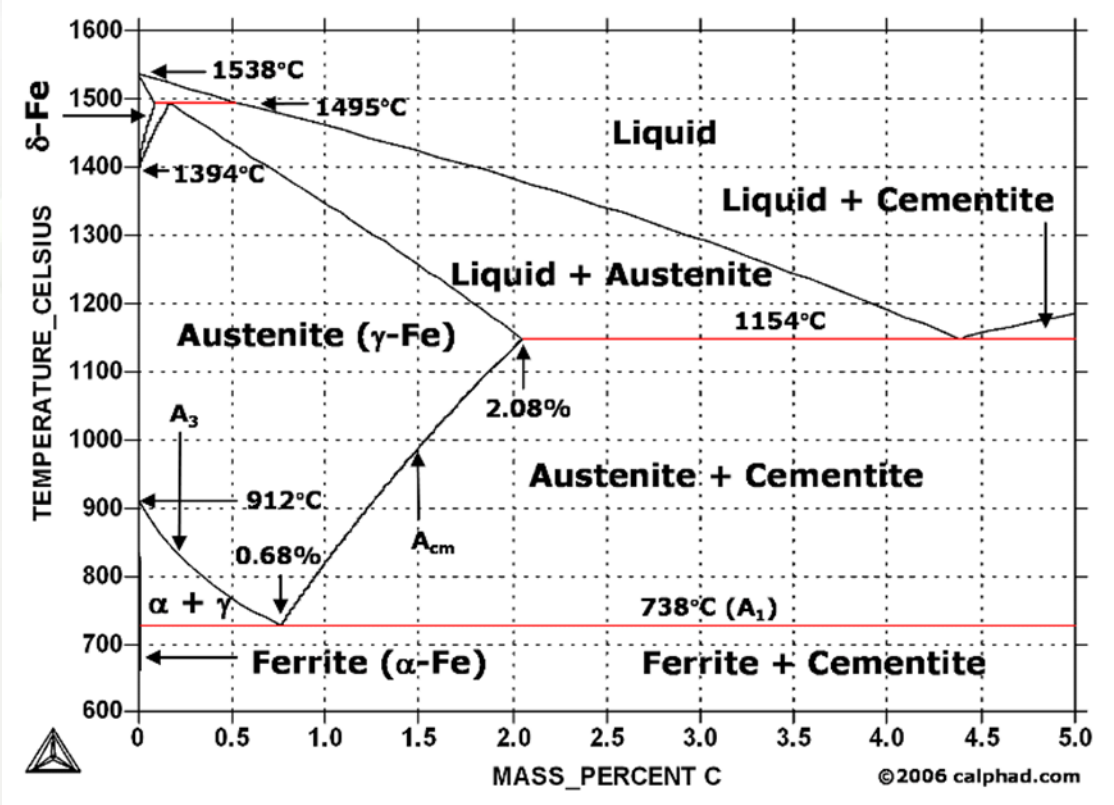
❖ Stress relieving technique

- **Residual Stresses in a Microstructural perspective**
  From liquid to solid state





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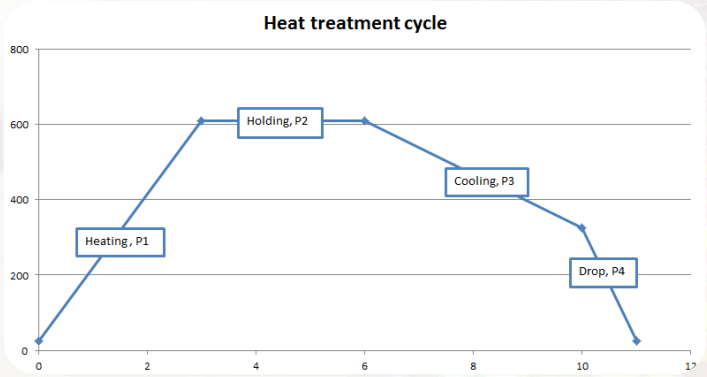
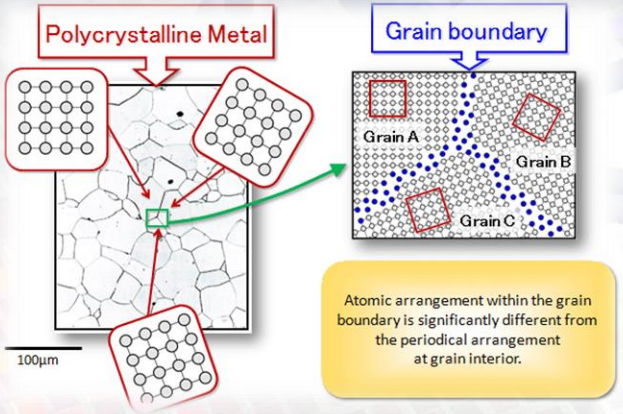
❖ Stress relieving methods

- **Stress Relieving - Various Means of Reducing Residual Stresses**

✓ Heat Treatment (TSR method):

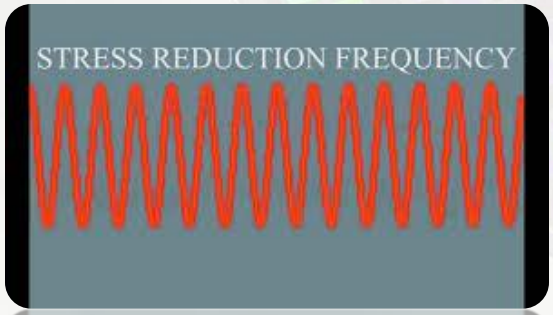
- Homogenous
- Expensive
- Time consuming
- Workpiece limitation

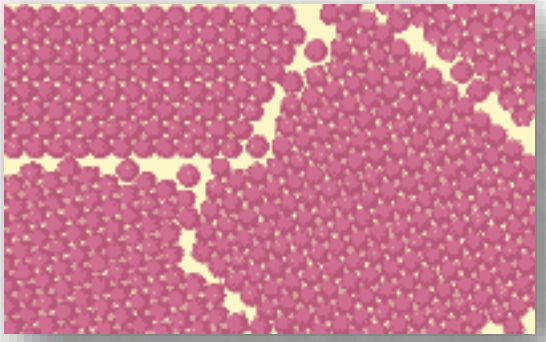




✓ Vibratory Stress Relieving (VSR method)

- Heterogeneous
- Not yet accepted as the industrial standard for stress relief
- Low cost and pollution
- Wide range of workpieces





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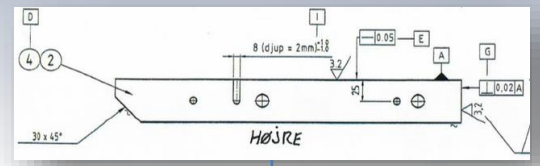
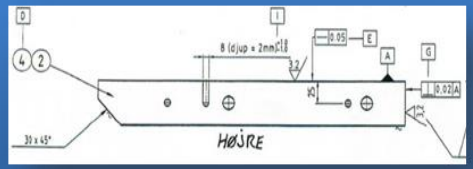
Microstructural characterization and analysis overview

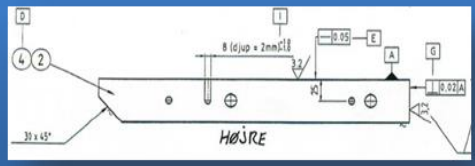


Microstructural analysis with metallography and SEM/EDS

Micro Hardness



TSR



VSR

Microstructural analysis with metallography and SEM/EDS

Micro Hardness

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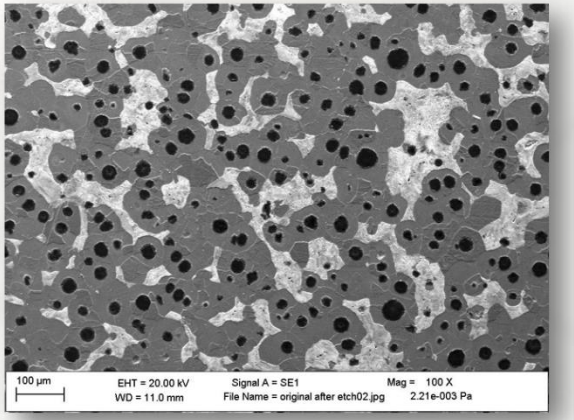
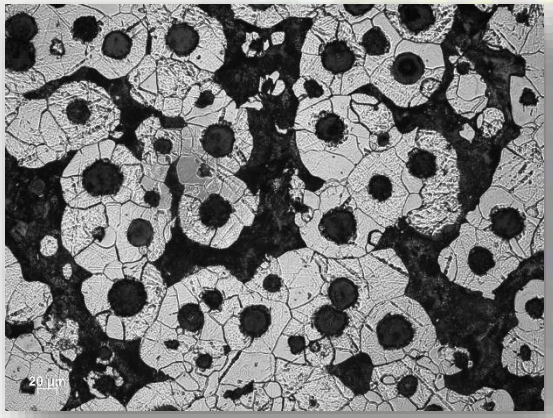
❖ Original sample identification

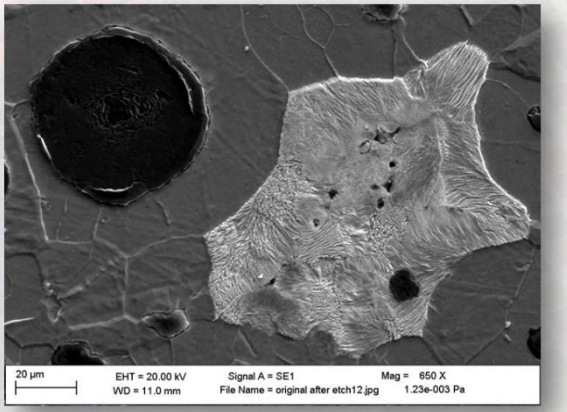
- ✓ The main microstructure consisting of ferrite, pearlite and nodules of graphite. As it is clearly observed, it is a heterogeneous distribution of pearlite structure in the ferrite matrix and there are clear difference in nodule sizes. The size of nodules is about 10-50 µm but they are mostly 25 µm in average and the ferrite grain size is approximately 25 µ in both areas.

Elemental analysis of as-received sample

Elements	C	Si	Mn	Cu	Fe
As received Original sample	˜4.5 (unreliable)	2.7-3.1%	0.4-0.5%	˜0.6%	Balance
Expected result according to standard	3.2-3.6%	2.2-2.8%	0.1-0.5%	<0.5%	balance







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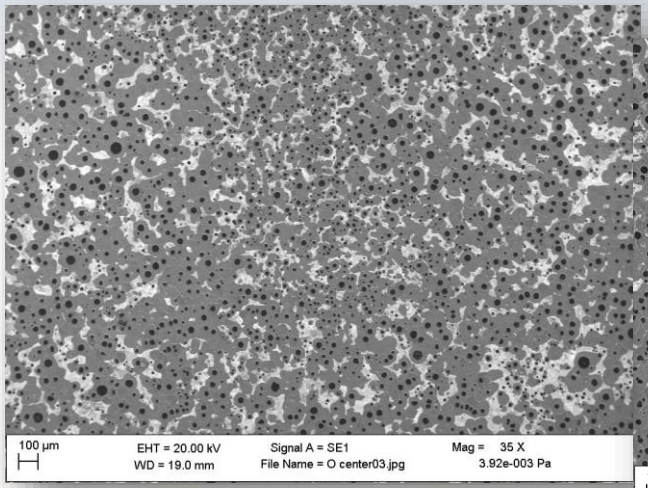
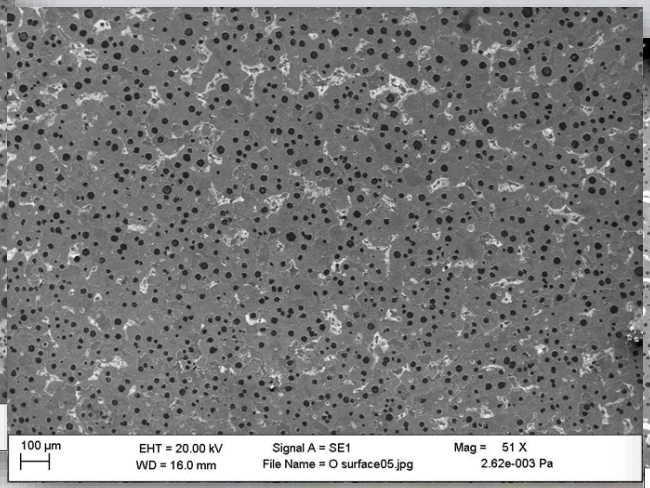
❖ Original sample identification

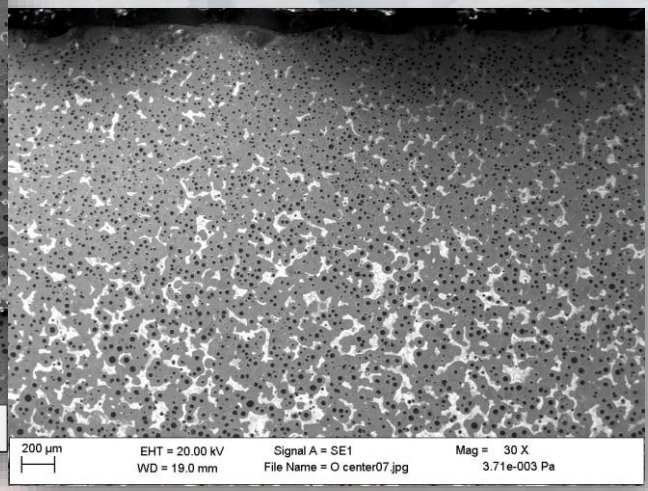
- ✓ The ratio of ferrite/pearlite is about 30% pearlite in the 70% ferrite matrix in the center and this ratio is about 20% perlite in 80% ferrite matrix near the surface.



Original sample, center.



Original sample, surface.



Original sample, cross section.

- ✓ The Micro hardness of specimens were measured in two different areas in a total of 10 points including center and surface of the sample (5 points in each area). The hardness of two areas, are shown in Table 1. In spite of different distribution of pearlite from center to surface of the sample, the Micro hardness amounts show no particular decrease.

Table 1: Average Brinell values obtained in two area of the original sample.

Area	1	2	3	4	5	Ave.
Center	149	137	141	138	139	140.8
Surface	136	138	138	148	149	141.8

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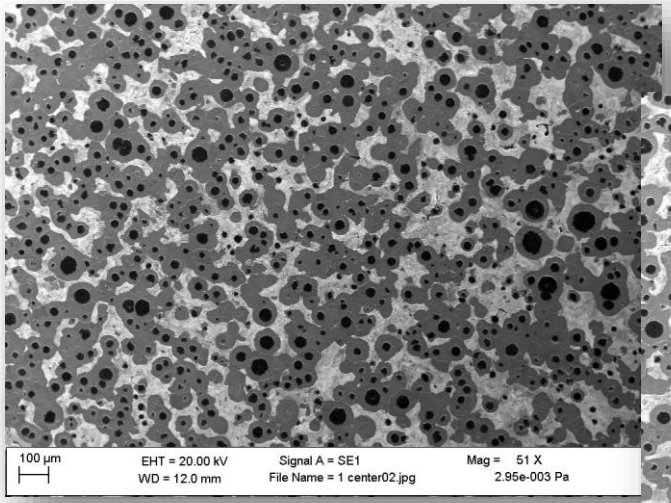
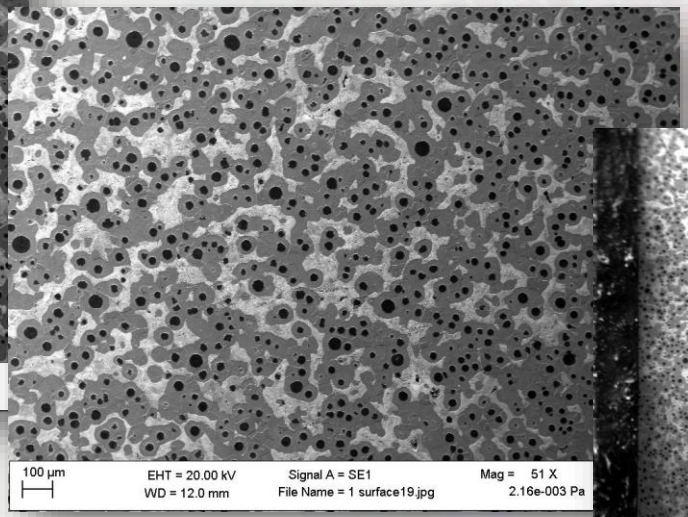
❖ Investigation and test results after heat treatment (TSR)

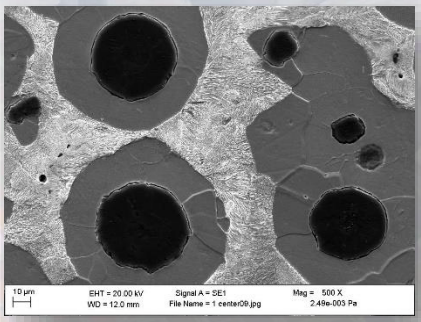
- ✓ The process is done simply by heating the flat bars up to 600˚C, keeping them for 3 hours in this temperature and cool them down. The main microstructure for TSR samples is the same microstructure of original sample including ferrite, pearlite and nodules of graphite. It is obvious that there are a change in the heterogeneous distribution of pearlite structure in the ferrite matrix compared to original sample. It means that, there is a homogenous distribution of pearlite in the ferrite matrix.

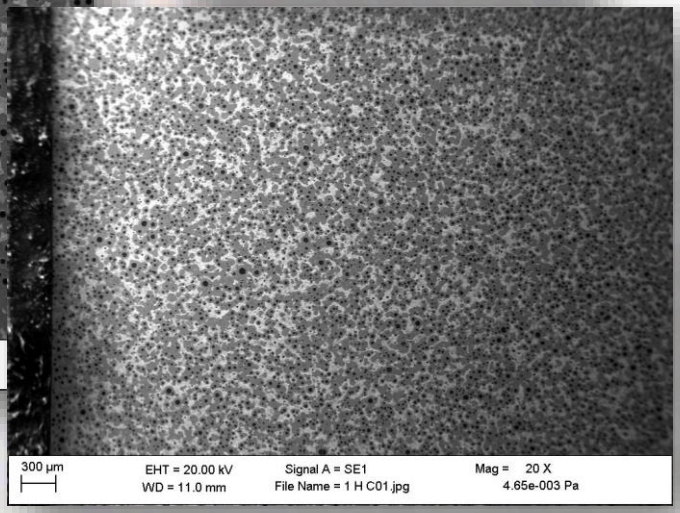


Sample after TSR, center.



Sample after TSR, surface.





Sample after TSR, cross section.

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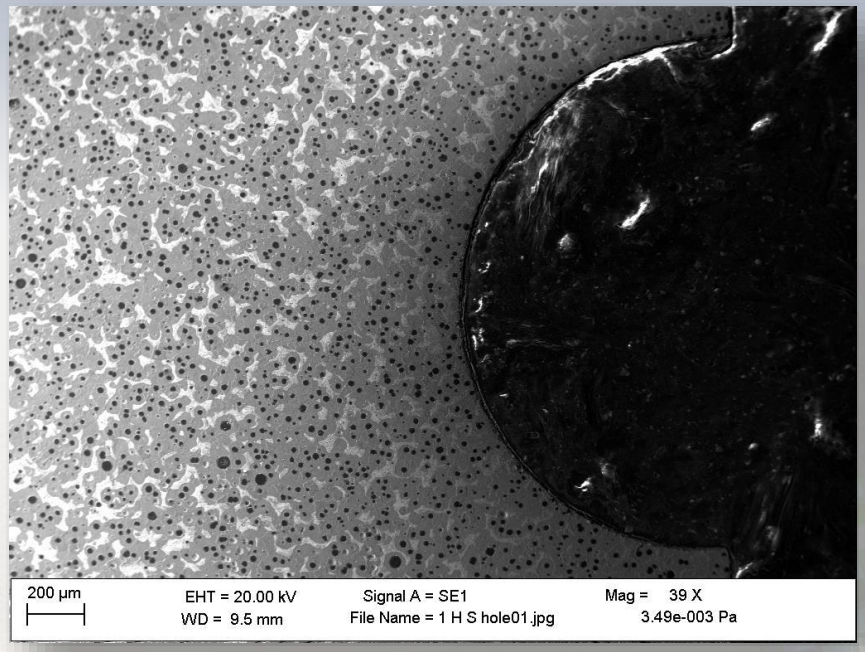
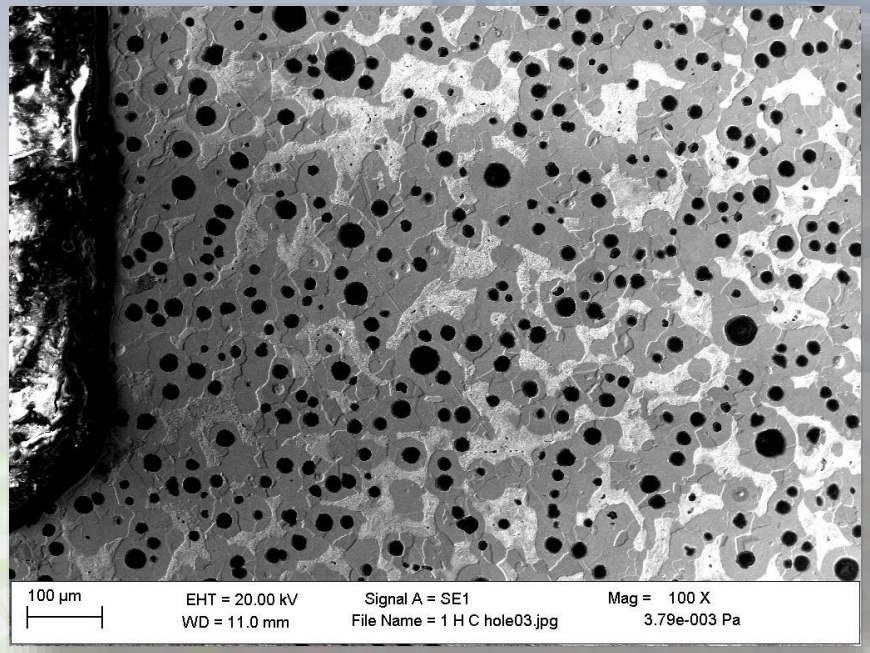
❖ Investigation and test results after heat treatment (TSR)



Hole drilling area from surface.



Hole drilling area from cross section.

✓ The Micro hardness of specimens were measured in two different areas in a total of 10 points including center and surface of the sample (5 points in each area). Comparing the original sample, the same distribution of pearlite from center to surface is observed and the average Micro hardness amounts show a little bit decrease in the both center and surface areas.

Table 2: Average Brinell values obtained in two area after TSR treatment.

Sample	Area	1	2	3	4	5	Ave.
Random cross section	Center	141	138	134	135	144	138.4
	Surface	135	137	137	141	135	137
Hole drilling area-cross section	Center	142	143	135	145	138	140.6
	surface	134	136	135	141	142	137.6

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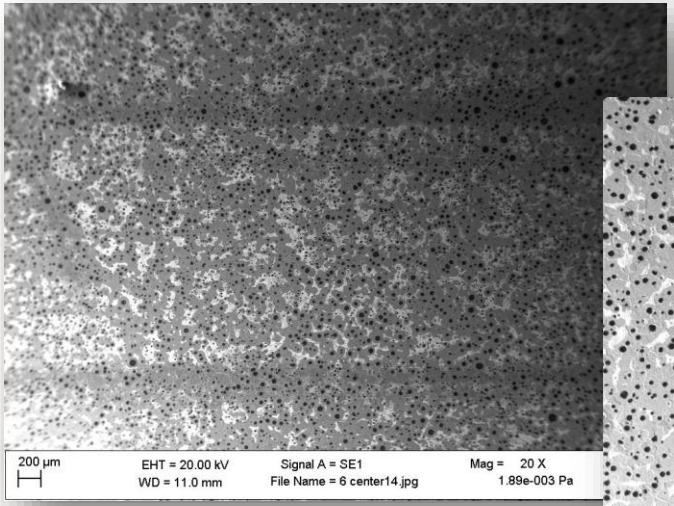
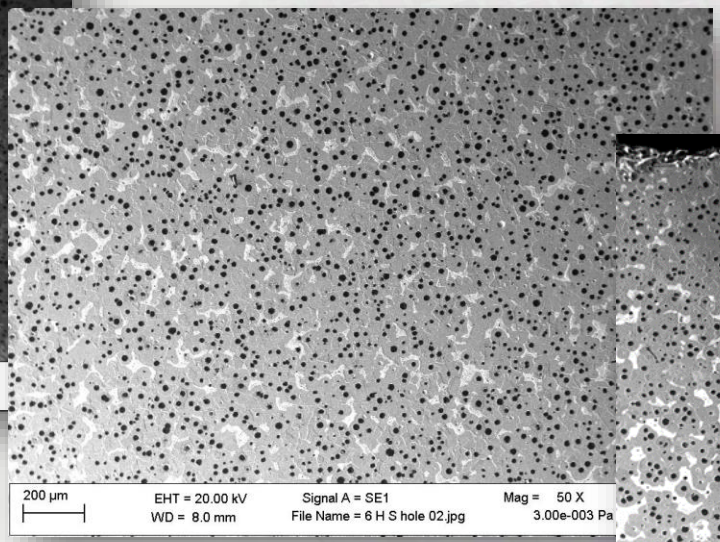
❖ Investigation and test results after vibratory treatment (VSR)

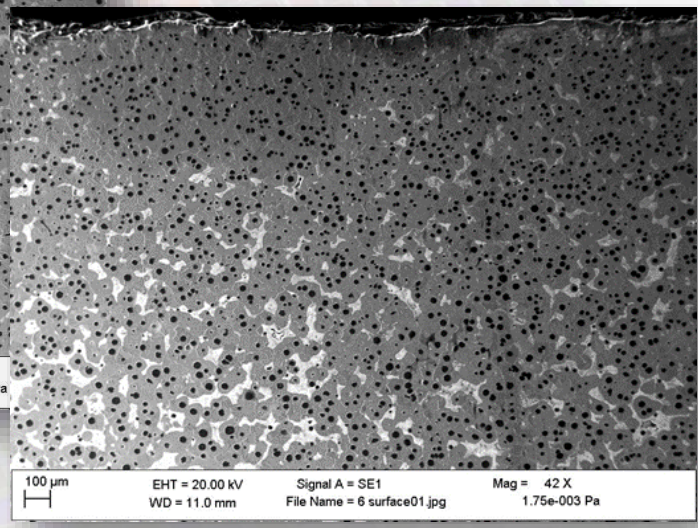
✓ The main microstructure for VSR samples is the same microstructure of original sample including ferrite, pearlite and nodules of graphite. it is obvious that there are not a big change in the heterogeneous distribution of pearlite structure in the ferrite matrix compared to original sample. Comparing the original sample, the ratio of ferrite/pearlite, nodule size and ferrite grain size are also similar in both center and surface of the samples. The only impressive change is that it has been observed some kind of change in the orientation of the pearlite packs in the center area. In other words, it seems that the pearlite packs try to be orientated in special linear direction. However, this change is not observed and confirmed in all of the samples.



Sample after VSR, center.



Sample after VSR, surface.



Sample after VSR, cross section.

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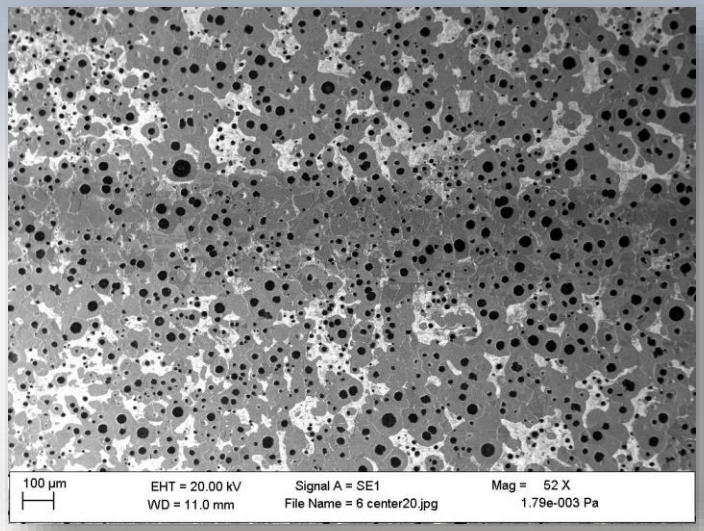
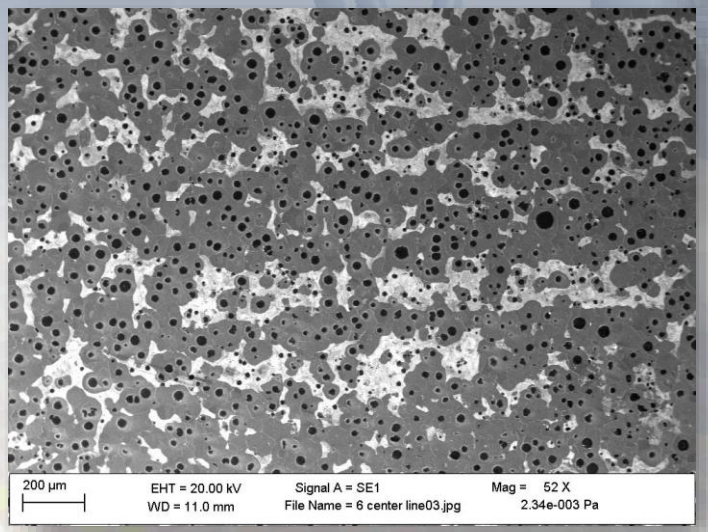
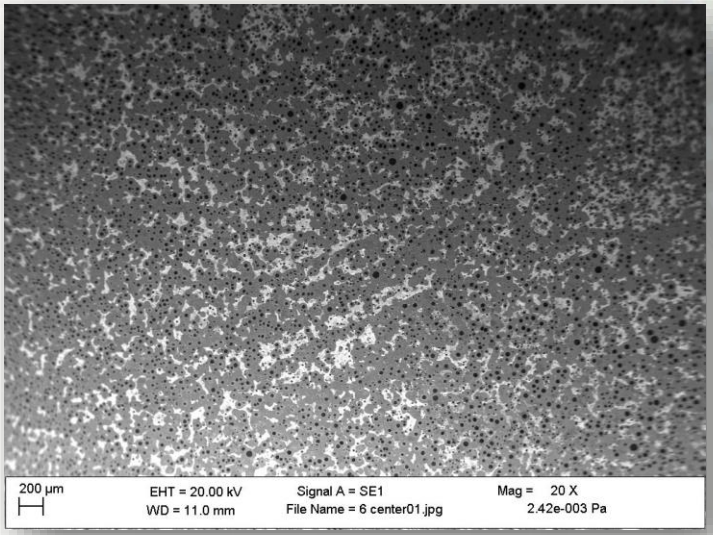
❖ Investigation and test results after vibratory treatment (VSR)



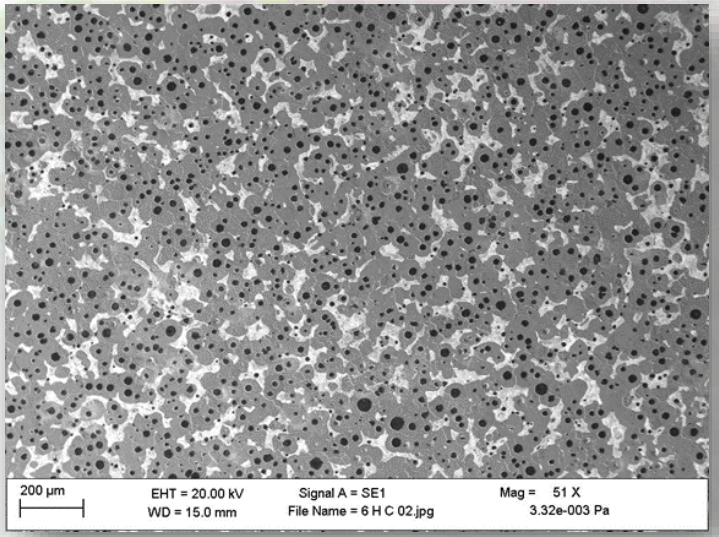
Sample after VSR, center.



Sample after VSR, center.



Sample after VSR, center.



Sample after VSR, center.

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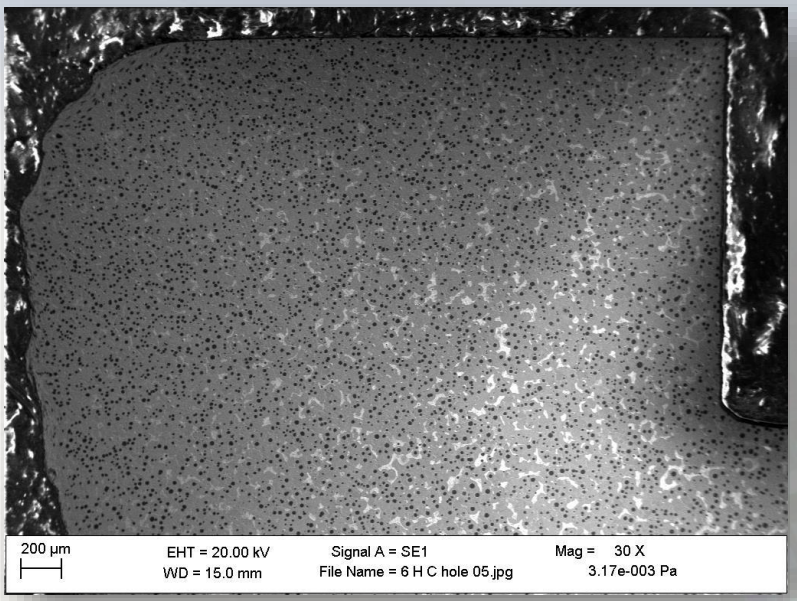
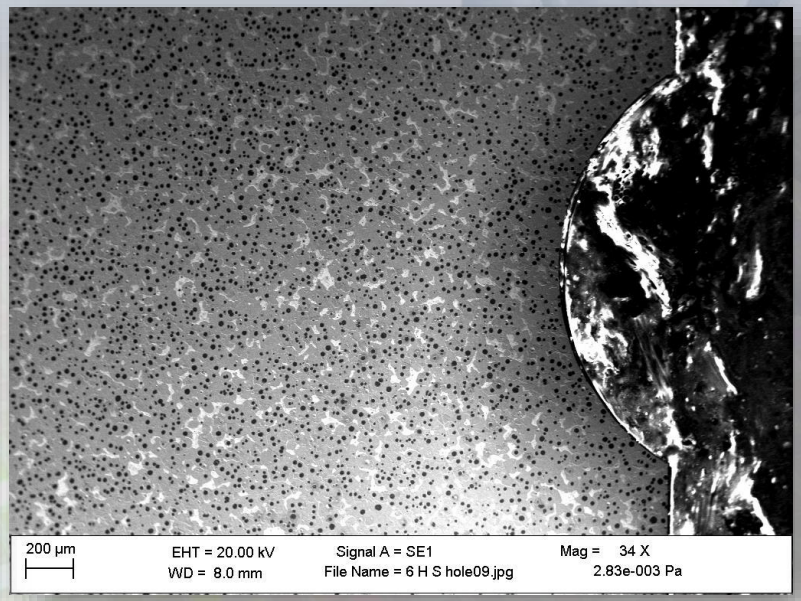
❖ Investigation and test results after vibratory treatment (VSR)



Hole drilling area from cross section.



Hole drilling area from surface.

✓ The Micro hardness of specimens were measured in two different areas in a total of 10 points including center and surface of the sample (5 points in each area). Comparing the original sample, the heterogeneous distribution of pearlite from center to surface is observed and the average Micro hardness amounts show no special decrease in the both center and surface areas.

Average Brinell values obtained in two area after VSR treatment

Sample	Area	1	2	3	4	5	Ave.
Random cross section	Center	144	139	138	143	139	140.6
	Surface	142	148	138	139	142	141.8
Hole drilling area-cross section	Center	140	145	138	142	138	140.6
	surface	134	135	139	138	139	137

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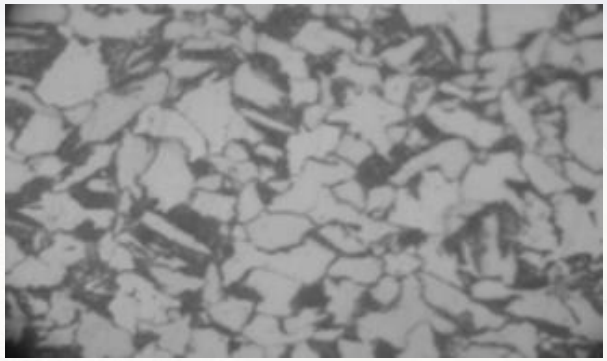
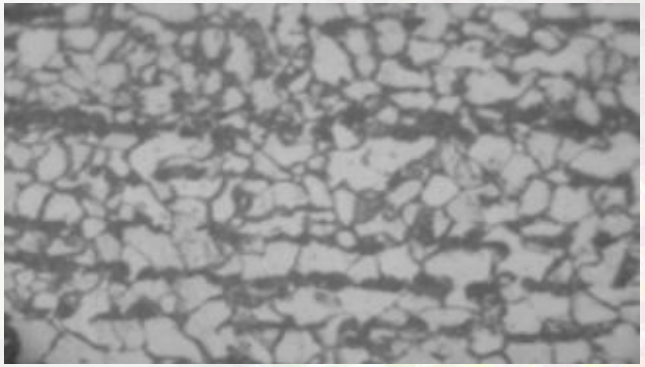
❖ Investigation and test results in related references

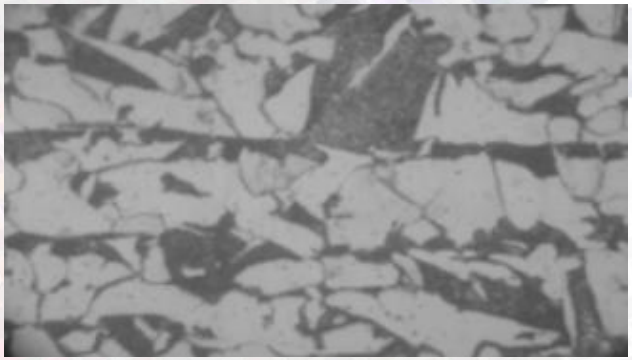
✓ Background
Microstructural changes in VSR treated specimens in references



non-stress relieved sample



vibration stress relieved sample



thermal stress relieved sample

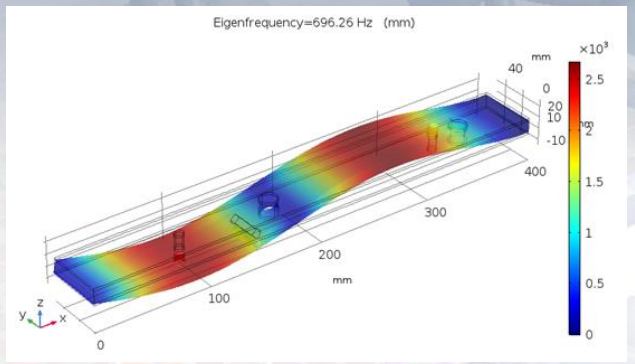
- ✓ Mehrabadi et. Al. (2012) VSR of welded carbon steel: Imaged the grain structure using optical microscopy taken from the Heat Affected Zone (HAZ)
- ✓ Munsi et. Al. (2001) made similar investigations and concluded: Grain refinement occurs and hardness increases in the high-amplitude vibrated specimens. The increase in hardness seems related to the orientation of the crystals.

❖ Conclusions

- ✓ From the identity of as received S8 samples, it is clear that this type of samples are heterogeneous in microstructure.
- ✓ Considering the results of Microstructure analysis for samples after heat treatment (TSR), it is obvious that TSR has completely approved for stress relieving.
- ✓ Considering the Micro hardness test for samples after heat treatment (TSR), results show better uniformity in all areas.
- ✓ Considering the results of Microstructure analysis for samples after vibratory stress relieving, some changes in orientation has been observed however, it is not completely confirmed in all areas and samples so, VSR is not yet accepted as the industrial standard for stress relief.
- ✓ Considering the Micro hardness test for samples after vibratory stress relieving (VSR), results show no special changes in different areas.

❖ Finite element analysis

The FEA on S8 shows changes in the stress state:



- Used a new FEA approach based on a set of material functions capable of describing the build up of residual stresses. The selected material functions are not verified against experiments nor scientific literature.
- In the current version of the model subsequent cooling during casting induce up to 40 MPa internal stresses. Final stress levels seems to be below 1 MPa.
- Mimicking VSR by inducing a shear wave excitation at 220 Hz at an vibration amplitude of 50 µm (not verified) will induce stress levels up 4 MPa
- Thus VSR stresses are well above the levels of residual stresses, but below the Yield stress of cast iron.

This indicate that VSR treatment on S8 should not work. The criteria for this is that the sum of residual stresses and VSR induced stresses are locally above the Yields stress (120 MPa).

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❖ Perspectives

- Including Nano indentation tests and EBSD analysis as a more accurate methods for analyzing the microstructure and hardness test seems to be very helpful.
- The evaluation of residual stresses is not an easy task and it can affect structural behavior depending on Materials type, size and configuration of the workpiece and manufacturing process. As a result, by changing these parameters such as choosing welding area in stainless steel material, the consequence would be absolutely different.


Thank you ...