ON THE ASSESSMENT OF MACRO INCLUSIONS IN STAINLESS STEELS USING ULTRASONIC TECHNIQUE

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Abstract: Determination of the inclusion size distribution in clean steels is a difficult task since the inclusion content is very low. This is even more pronounced for inclusions in the size range between 30-100 microns. Depending on the steel application the inclusions might cause fatigue failure or rupture. The use of light optical methods for the assessment of macro or semi macro inclusions in such steel grades is not beneficial since finding sufficient number of inclusions for statistical calculations, is a very time consuming process. The application of ultrasonics with immersed scanning high frequency transducers has proven to be an excellent tool for this purpose. This technique is now used as a standard tool by a producer of ball bearing steels. However, for stainless steels there are limitations of the ultrasonic technique. In this study examination of different stainless steel grades has been done and it clearly shows that the austenitic crystal structure attenuates the sound wave to such an extent that the inclusions detected are hidden behind the background noise. This is more or less independent of the grain size. The overall result is that Ultrasonic examination for the assessment of macro and semi macro inclusions is a reasonable method for stainless steel grades with other structure than austenitic.

Introduction: Earlier work(1-6) has shown that ultrasonics is a suitable method for the detection of macro inclusions in carbon steels. By the use of conventional ultrasonic technique with an immersed focused 50 MHz 0,5" high frequency transducer, inclusions from the size of approx. 30 μm are detectable. The ultrasonic technique is thereby a relatively quick method to assess the inclusion size distribution. Due to the volumetric penetration of the ultrasonic testing, the method is especially good when examining clean steels where the concentration of inclusions in general and macro inclusions in particular is very low. The visibility of the inclusions is very good as can be seen in figure 1.

Unfortunately the ultrasonic technique has shown to be less suitable for similar examinations of austenitic stainless steels. This is shown in such a way that the noise reaches such levels that the inclusions become hidden in the background noise. The coloured background is super-positioned by a yellowish-greenish colour representing the background noise and the possible inclusions are no longer visible which is evident in figure 2.

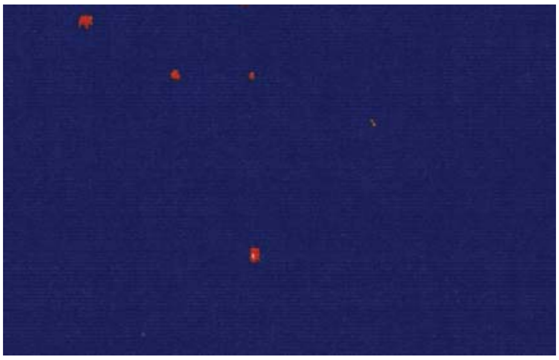

Figure 1. Graphic presentation of an US-scanning performed with a 50 MHz transducer. Steel grade: 100Cr6 (ball bearing steel).

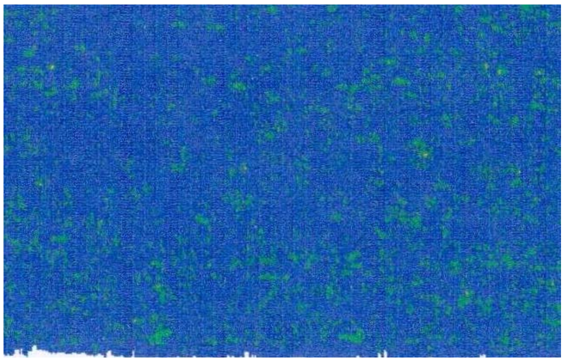

Figure 2. Graphic presentation of a US-scanning performed with a 50 MHz transducer. Steel grade: AISI 304.

As a first move in this study some effort has been put on the analysis of the influence of the austenitic grain size on the background noise level. The grain size in stainless steels can be of the same size as the inclusions studied. A sample taken in the ladle at Outokumpu Stainless in Avesta was first analysed with light optical microscopy, LOM. The sample was thereafter hot rolled after reheating to

1200˚C. A quadratic sample has then been cut out and the remaining sample is then annealed at a temperature of 1020˚C and a second sample is cut out. After the annealing operation the sample is cold rolled to approx. 25% area reduction. The sample is then cut in 5 pieces of which 4 have been annealed at 1020˚C for different annealing times before cooling in water. The last annealing has been performed in order to get a recrystallised structure in the material. The longer annealing times should have given a substantial grain growth in the sample. At a later stage the evaluation of the grain size has been performed at Outokumpu Stainless in Avesta. After rolling and heat treatment the samples have been analysed with high frequency ultrasound at Ovako Steel in Hofors, using a Krautkramer USIP 20 HR as ultrasonic instrument. The scanned area is approx. 430mm^2 and the volume is approx. 215mm^3.

Next step was to study the noise level of ultrasonics using a high frequency transducer in different crystal structures in stainless steels. Ultrasonic examination of austenitic, ferritic, duplex(ferritic-austenitic) and martensitic stainless steel grades was performed in order to find out how strong the influence of the crystal structure is on the level of the background noise. The work has incorporated light optical microscopy for determination of grain size, crystal structure and inclusions. Further, the immersed scanning high frequency ultrasonic technique has been used for determination of the noise level during ultrasonic examination for the assessment of macro inclusions. In this case the scanned area is approx. 2000mm^2 and the volume is approx. 2200mm^3.

Results: The results from the first study, comprising ultrasonic examination of the austenitic grade AISI 304 with different grain sizes, are presented in Table 1 together with the grain sizes. As reference some data are used from a charge of 100Cr6, a ball bearing steel, examined with the focused 50 MHz 0,5” transducer. Since the scanned area as well as the thickness of the scanned layer differ between the reference and this examination the results are not fully comparable. The thickness of the scanned zone is dependent of the thickness of the sample. The surface roughness and parallel sample surfaces are essential for good results.

Table 1. Results of ultrasonic examination as well as determination of grain size of austenitic stainless steel (AISI 304)

Sample No.	**Condition**	**Annealing time [min]**	**Grain size**		**Noise level [%]**
			ASTM E112, indexG	Mean grain size [µm]	
A	Cold rolled	0	Deformed grains		22,1
1	Cold rolled/annealed	2	7	31	21,7
2	”	4	6	44	22,2
3	”	8	5	62	23,7
4	”	16	4,5	74	24,6
B	”	32	-	-	23,4
O	Hot rolled/annealed		5,5	53	23,2
Ref 1	”		10-11	8-10	15,3
Ref 2	”		10-11	8-10	16,3

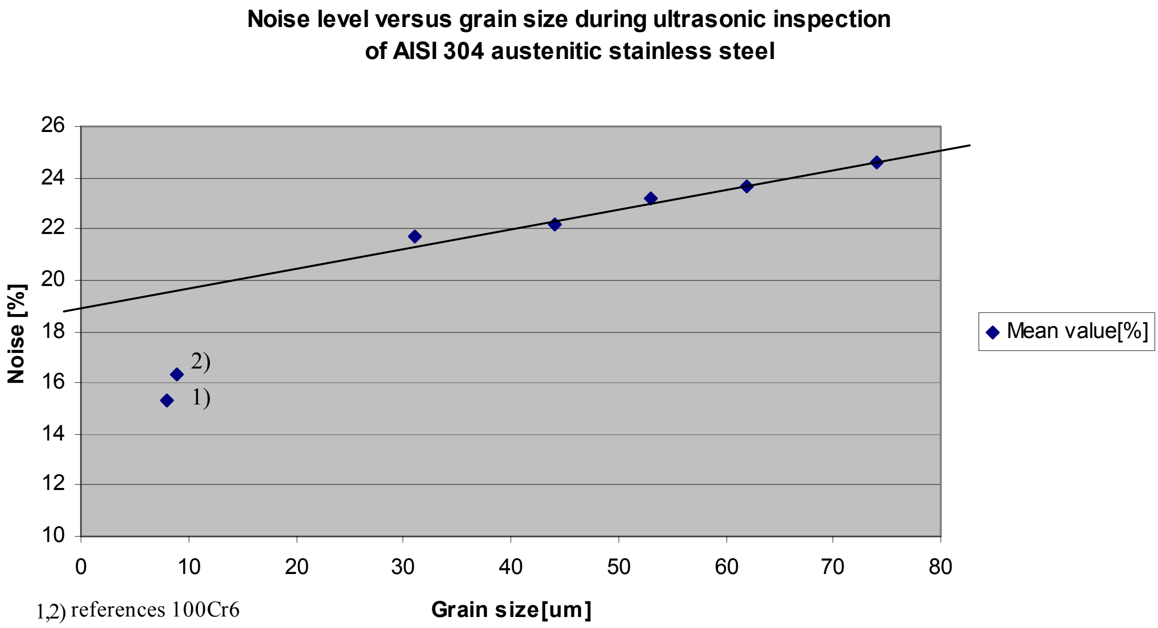

Figure 3. Noise level as a function of the grain size for AISI 304, austenitic stainless steel.

Noise is also called grass or more correct scattering and is the result from numerous grain boundaries at which the sound waves are reflected or transmitted. This scattering is one of the components in what is called attenuation, the others are diffraction and absorption. Scattering cannot be counteracted with increased effect from the transmitter because the grass level also rises. The usual (or only means for most application) method to decrease the scattering is to change to lower testing frequencies, however at the sacrifice of resolution.(7) In figure 3, the noise level as a function of the grain size for AISI 304, austenitic stainless steel is presented. The noise levels for the austenitic grains seem to be a linear function and show that there is a connection between the grain size and the noise level from the ultrasonic test. It could be of interest to note that the noise level is somewhat lower for the sample with the longest annealing time. The variation in grain size can be seen in table 1. The reason why the noise level diminishes could be that the contribution from the attenuation of the ultrasonic wave diminishes for the largest grain size. This is probably due to the fact that the austenitic grains have become that large that they do not interfere, to the same extent, with the wave length.

Since the variation in austenitic grain size did not seem to fully explain the difference in noise level between the austenitic steel and the reference material the influence of the crystal structure was examined in the second part of the present work. Here, the graphic presentations of the ultrasonic examinations can be directly compared since the thicknesses as well as the surface roughness are the same for the samples.

Table 2. Metallographic examination

Sample	Steel grade	Structure	Grain size		Comment
			ASTM E112, indexG	mean grain size [µm]	
THF439	AISI 439	Ferritic	9	16	Ti-stabilised
	2205	Ferritic-austenitic	*		Duplex structure
THM10	AISI 430	Martensitic	9	16	Hardened
THM98	”	”	7	31	”
THA	AISI 321	austenitic	9,5	13	Ti-stabilised

* Grain size is not applicable

The microstructures of the two Ti-stabilised grades (ferritic and austenitic, respectively) are illustrated in figures 4 and 5 respectively.

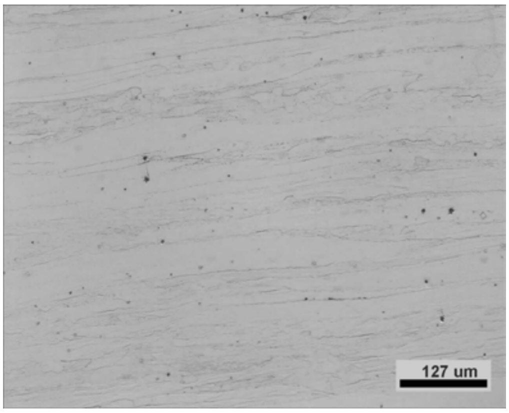

Figure 4. Microstructure of AISI 439 Ti stabilised ferritic stainless steel

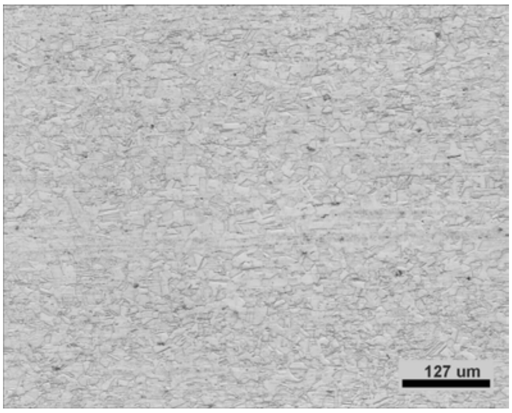

Figure 5. Microstructure of AISI 321 Ti stabilised austenitic stainless steel

The result of the ultrasonic examination of the samples of different stainless steel grades with different crystal structures is summarised in table 3.

Table 3. Result of the ultrasonic examination

Steel grade	Sample	Structure	Condition	Noise level	Comment
AISI439	THF439	Ferritic	Partly crystallised	Slightly more noise	Ti-(C,N) uniform distrib.
2205		Ferritic-austenitic	Hot rolled	Little noise	Several inclusions
AISI430	THM10	Martensitic	Hardened	Very little noise	few inclusions
”	THM98	”	”	”	”
AISI 321	THA	Austenitic	Annealed	Very little noise	Ti- (C,N) uniform distrib.

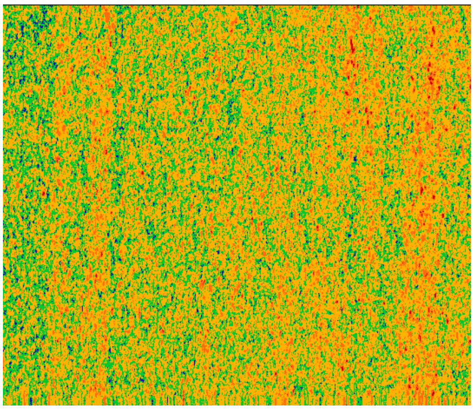

Figure 6. Ultrasonic Scanning with a 50 MHz transducer of AISI 439, ferritic Ti-stabilised stainless steel

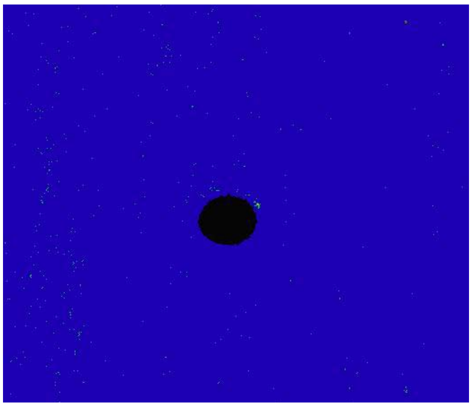

Figure 7. Ultrasonic Scanning with a 50 MHz transducer of AISI 321, austenitic Ti-stabilised stainless steel

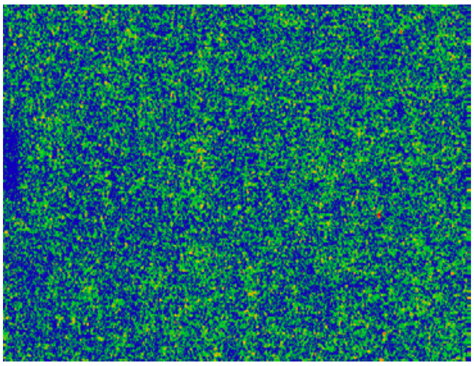

Figure 8. Ultrasonic Scanning with a 50 MHz transducer of 2205, a duplex (ferritic-austenitic) stainless steel

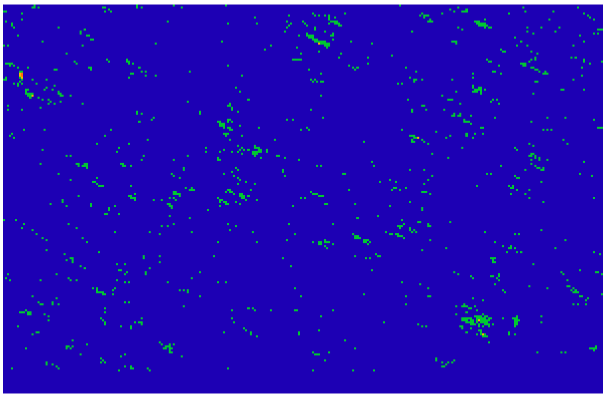

Figure9. Ultrasonic scanning with a 50 MHz transducer of AISI 430, a Martensitic stainless steel, grain size 16 μm.

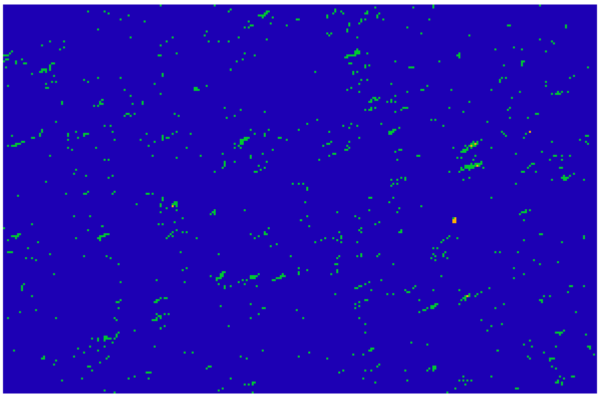

Figure 10. Ultrasonic scanning with a 50 MHz transducer of AISI 430, a Martensitic stainless steel, grain size 31 μm.

Discussion: There is evidently a connection between the austenitic grain size and the noise level in ultrasonic examination of stainless steel. If the noise level for AISI 304 is extrapolated towards smaller grain sizes as shown in figure 3 the noise level would still be much higher than for the reference material at a similar grain size. Most probably the difference in noise level between austenitic stainless steel and ball bearing steel is to some extent to be explained by different crystal structures in the different materials. It is likely that the crystal structure in the austenitic phase affects the noise level more than the ferritic crystal structure in the ball bearing steel does.

Concerning the results of the ultrasonic examination of stainless steels with different crystal structures some interesting observations were made. The martensitic samples, figures 9 and 10, show a very low noise level. The noise level is more or less independent of the grain size at least in the range 15-30 μm. The ferritic sample on the other hand shows a somewhat larger noise level but has also a pronounced striped structure which might be related to the textured structure of the grains, figure 6. The typical inclusions are the Ti(C,N) precipitates but they are of micro size. These micro inclusions are randomly distributed. The austenitic Ti- stabilised sample, illustrated in figure 7, gives a low noise level, which might be due to a fine-grained structure (about the same level as for the ball bearing steel samples). As for the ferritic Ti-stabilised steel there are uniformly distributed Ti(C,N) particles.

The noise level in the duplex steel seems to be positioned in between the noise level in martensitic and ferritic crystal structures, figure 8. However, some relatively large inclusions are visible in the duplex steel.

Further, the present work reveals the importance of basic material data in ultrasonic examinations. Such data are type of material, material condition (rolled, annealed etc), crystal structure, grain size etc.

Conclusions:

- The noise level is more or less independent of the grain size (within reasonable limits) for martensitic steel grades
- There seems to exist a distinct relation between crystal structure and noise level in the grain size range from 30 microns and larger
- Ultrasonic examination is suitable for the assessment of macro inclusions in non-austenitic stainless steel. However, ultrasonics seems to be a method of value for extra fine-grained austenitic stainless steel
- Basic material data (type of material, condition, crystal structure etc) are needed in evaluation of ultrasonic examination data
- The present work is an initial study regarding the possibilities with the high frequency transducer technique for stainless steels with different crystal structures. The experience obtained can be used for initiation of further development work

References:
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