Quench water quality: thermal impact estimation

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Abstract

A lack of control of the quenching water quality may imply possible quality consequences such as quench cracks, lack of hardness or an insufficient "as quenched" thermal homogeneity on the carbon steel. The quenching medium can be polluted by agents e.g. mechanical oil, free gas in the water or products scale which could modify the cooling efficiency of the water. Filtering systems or degassing tanks are installed on the process water recirculating systems to mitigate these issues.

In this context, a test routine compliant with the norm ISO 9950 has been prepared to evaluate the thermal impact of pollutants on the quench severity. The set-up consists of a bath filled with demineralized water, a furnace, a data recorder connected to the instrumented sample and the support for the sample. We have investigated the following pollutants: free gas, mechanical oil, and a mix of steel scale and mechanical oil.

Results are analysed taking as reference the 100% "demineralized" water quench. The trials are performed under static conditions: calm cooling medium and no movement of the sample during quenching. We can assume that these pollutants intrinsically affect the cooling power of the water.

The trials aim to show a global statistical behaviour of the impact of the different pollutants that can increase or decrease the normal cooling rate. That analysis can help in the choice of the criteria for quenching recirculating system maintenance accordingly with the optimal thermal performance of the process.

Keywords: Quench quality, water pollutants, cooling, natural convection.

1. Introduction

Since many years the thermal characterisation of the heat treatment quench for carbon steel is a key topic in the industry. The cooling medium is one of the factors that can influence this process. It plays an important role in the quality of the cooling and the physical properties of the as-quenched products.

The lack of control of the water quality may imply consequences such as quench cracks, lack of hardness or an insufficient as-quench homogeneity. Hence, this document analyses "***qualitatively***" the impact of different pollutants in the cooling medium (here water) on the quenching severity, measured in terms of cooling rate, rather than by heat transfer coefficient (HTC) in w/(°C m^2) / thermal conductivity (K) in W/(m. K) rate expression proposed by Grossmann [3]. Indeed, we used the same material for all the trials. Hence, only the HTC will vary as a function of the pollutants.

The additives/pollutants chosen for this experience are based on the Vallourec experience on pollutants control: industrial oil, particles of scale, and free gases. The reasons for these three pollutants are:

- The fact that lubricant from moving machines is often present in process water,

- The residual and not filtered scale (after descaling process) that can fall down and recirculate in process water

- The gas that is caught by the water from ambient air (ex: during product quick immersion) or product surfaces and that is not immediately released

2. The quench severity

The quench severity evaluates the cooling power of a quenching medium. The medium can have a change of state (very often from liquid to vapour) during quenching, specifically in the zones close to the hot surfaces. This change of state stands for a significant variation of the cooling power, which can be divided into 3 stages/phases [1]:

- **Stage N°1 - Vapour blanket**: Vapour film surrounds the sample. It insulates the hot surface like a blanket reducing the heat flow from the hot body to the quenching medium. The heat transfer is mainly performed by radiation and conduction.

- **Stage N°2 - Nucleate boiling**: The previous vapour film finally collapses. That allows a high heat exchange rate by direct contact between the hot body and the quenching medium.

- **Stage N°3 - Convective cooling rate**: The temperature on the surface reaches approximately the boiling temperature of the quenching medium.

Stage N°1   Stage N°2   Stage N°3
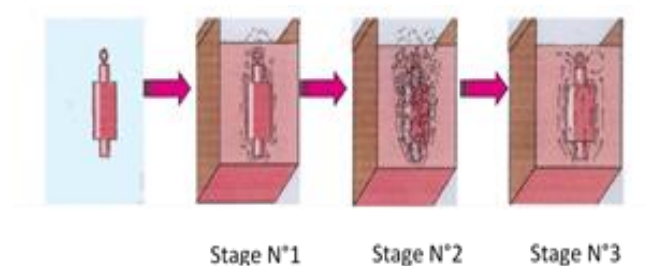
Figure 1 : Stages during quenching [1]

3. Process and set-up

Figure 2 shows the set-up for the trials inspired by the ISO9950 Norm. It consists of a bath filled with demineralized water (1), a furnace (2), a data recorder (3) and support for the sample (4).
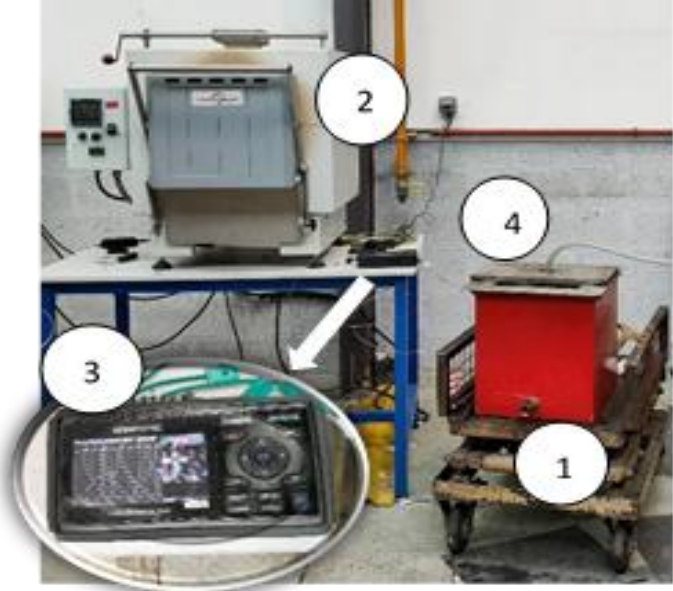

Figure 2: Trial's Set-up

The sample is a cylinder made of Inconel 600 connected to a support; the axis of the cylinder is drilled for positioning a thermocouple at 36mm from the sample head, such as the Norm ISO 9950 recommends [2]. This norm gives a reference for the quenching oil quality check, as no reference norm exists for quenching water quality checks. we used the same sample and precautions for this experience.
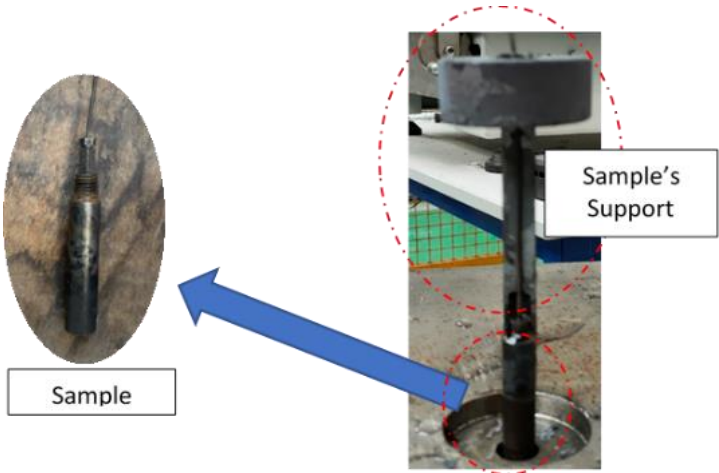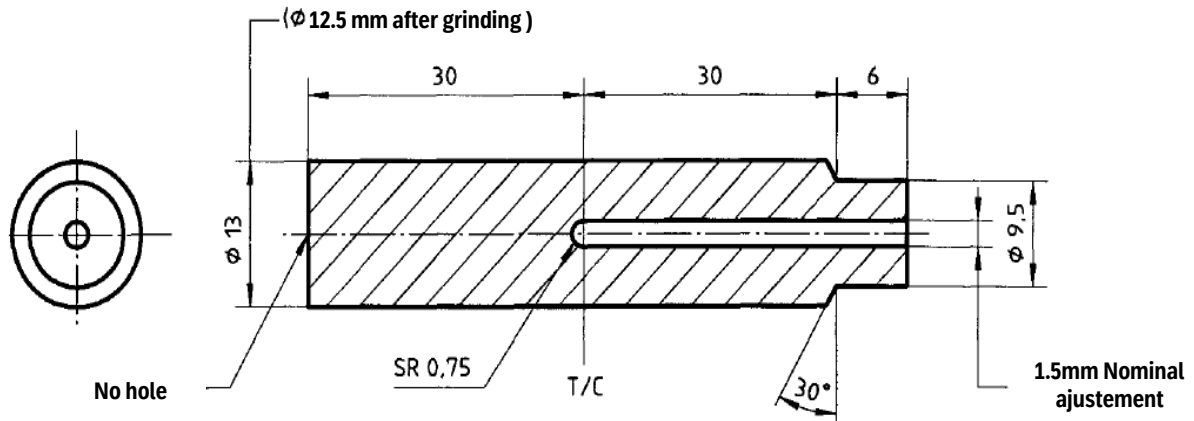

Figure 3 : Sample and support

Figure 4 : Sample's drawing

Trials are performed with the 3 pollutants in the quenching medium. Free gas, scale particles and industrial oil are added to the demineralized water separately before quenching. Concerning the scale case, it is actually a mix of scale particles and mechanical oil. This mix makes possible the scale particles presence on the water surface. Otherwise, scale particles fall at the bottom of the bath and no impact can be measured. Concerning the free gas case, it is applied for 15 minutes before quenching to keep the "static" quenching conditions for all the trials.

Table 1 shows the quantity of each pollutant for 42L of demineralised water.

Additive pollutant	Quantity		Observation
Free gas	0.4 bar (8.4 m/s)	0.6 bar (10.3 m/s)	It corresponds to the outgoing flow/pressure from the cylinder of gas
Mechanical Oil	1L	2L	It stands for 2.5% and 5% of the tray capacity
Scale (mix scale + oil)	1 L of oil + 0.5 Kg of scale		Oil is inserted in order to keep the scale in suspension on the surface

Table 1: Additive for trial

4. Results

Figure 5 groups the available data for the analysis of the demineralized water case. The results from this trial are taken as a reference. Five trials were previously done to stabilize the sample surface [2].

Each case is composed of 5 trials and performed from the same initial temperature (around 900°C). As discussed, the key-value from each curve is the cooling speed peak that intrinsically represents the maximum HTC value.

The results corresponding to tests with oil at 2.5% and 5%, free gas and the scale + mechanical oil mix trials were plotted under the same format.
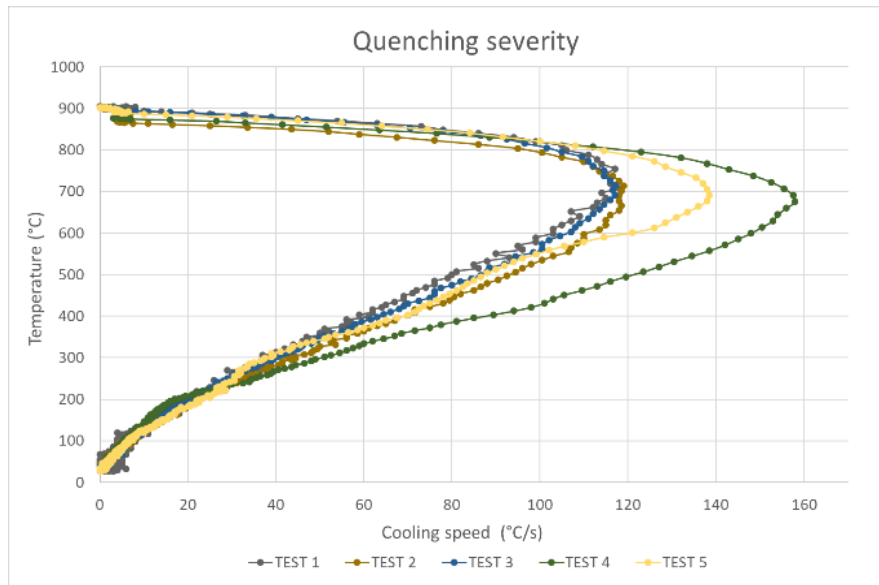
Figure 5: Demineralised Water Case

5. Discussions

In general, the data depict a measurement dispersion. This is due to the difficulty in controlling the beginning of quenching features (dip angle, initial temperature), the repeatability of the operators and the measurement of the stage transition. This is also due to the "local" effect of these pollutants in the water as they are not miscible in water; for this reason, we expect a global cooling homogeneity loss and consequently a reduction of the homogeneity of the mechanical properties from their presence. Hence for a first analysis, we compare the average of the maximum cooling rates values for each case. The following graph allows the analysis of the data distribution and the "qualitative" comparison of the impact of the different pollutants versus the maximum cooling speed value.
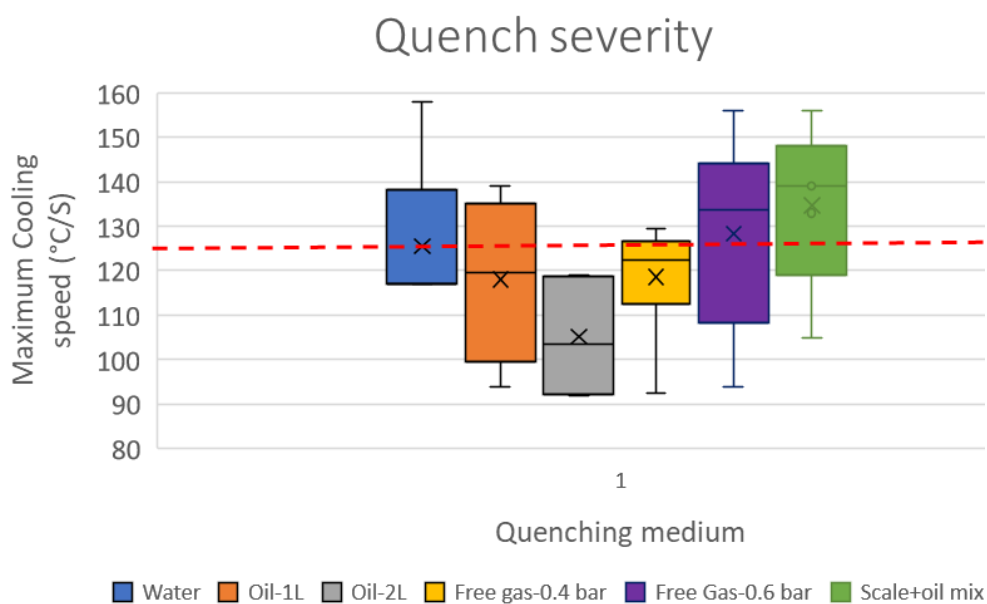

Figure 6: Quenching severity comparison

In [5], the author introduced the alteration of the cooling kinetics in water caused by the small presence of "substances" or contaminants compared to distilled water. Their effect is exerted on the persistence of the vapour blanket. According to their impact on the vapour blanket persistence, the contaminants are divided into two groups: increasing or decreasing effect. Oils and soaps are included in the first group, which means the vapour blanket vanishes at lower temperatures. Gases are part of this group but their influence is weaker.

Thereafter, we expected that the presence of pollutants such as mechanical oil and free gas ***reduces the cooling power of the quenching medium*** (demineralized water), which is observed in the average analysis in Figure 6. Nevertheless, the trend is ***slightly opposite*** for the mix scale+ mechanical oil case. One of the explanations is that the scale could create a condition of "higher roughness" at the surface, increasing the heat exchange, decreasing the vapour blanket persistence and boosting slightly the cooling process (see Figure 7)
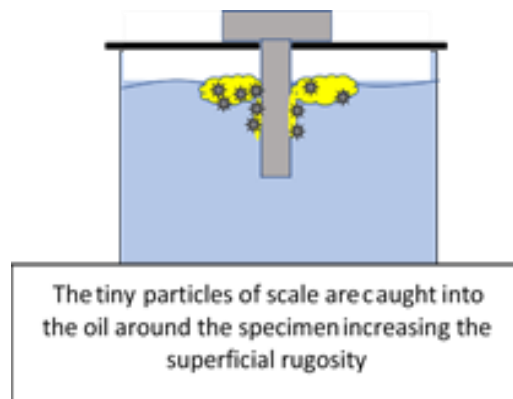
The tiny particles of scale are caught into the oil around the specimen increasing the superficial rugosity

Figure 7: Scale particles + oil mix: schema

We observe that the case where 0.6 bar of free gas (high turbulence inside the bath) is injected into the tank exhibits no relevant impact on the cooling power compared to the demineralized water case. In another word, that implies the gas was not caught inside the water before quenching performance. We explained that by a "splashing" phenomenon, which makes the free gas residence in the water difficult (see Figure 8). That means, no big changes compared to the water case. Remember that the gas injection only takes place only before the measurement phase, so unagitated quenching.
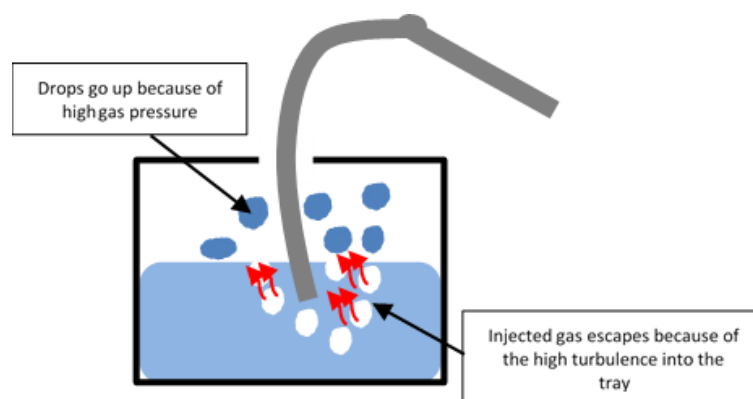
Drops go up because of high gas pressure

Injected gas escapes because of the high turbulence into the tray

Figure 8: Splashing phenomenon under high pressure

The literature is poor in data about water quench pollutants, the effect that is well documented is water temperature (considered as a process "pollutant" as it is linked to the process water cooling devices downsized in the plants or the effect of the hot seasons). Nevertheless, the tendency for oil is coherent with the global literature [4]. Indeed, if the 2.5%

and 5% of oil in water cases can be assimilated like colloidal addition, our results follow the same tendency depicted in Figure 9.
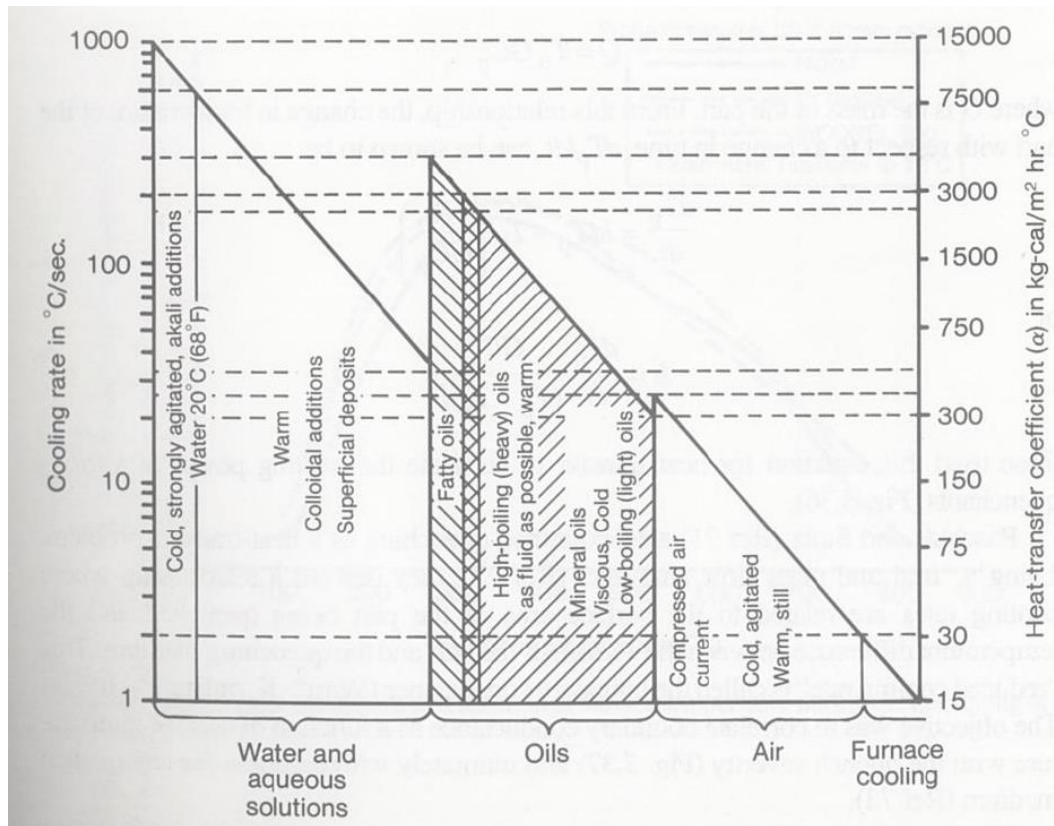

Figure 9 : Cooling power of various quenchants and heat-transfer coefficient at a probe temperature of 500°C [4]

6. Conclusion

The quality of the quenching medium plays an important role in the final properties. Hence, the document analyzes "**qualitatively**" the impact of different pollutants e.g. mechanical oil, scale particles, and free gas in the cooling medium (here demineralized water) in terms of quenching severity, here measured in the cooling rate rather than in HTC [4].

The results show that the cooling power globally decreases under the presence of pollutants such as mechanical oil and free gas. However, for the mix scale+ mechanical oil, the result presents an opposite tendency. Nevertheless, these average tendencies are the macro result of a global cooling homogeneity loss and consequently a loss of the homogeneity of the sample mechanical properties from the presence of the pollutants.

The trials are performed under static conditions (calm cooling medium and no movement of the sample during quenching). We can assume for dynamic processes that pollutants/additives in the initial cooling medium affect the cooling power in a similar qualitative way.

7. Reference

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