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# Deliverable D2.1:
# Selection and fabrication of the steels

## ShotTempering

Shot Peening Integration in Tempering Processes of Steels
for Enhanced Fatigue Performance

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**Project Abstract**

In response to pressing challenges, such as climate change and the increasing need for enhanced energy efficiency in the transport sector, the ShotTempering project addresses the imperative for advancements in the production process chain. This project introduces an innovative hybrid technique known as "warm peening," which integrates shot peening within the tempering treatment of components, primarily for high-demand applications like electric vehicles (EVs). EVs impose substantially higher loads on their components, necessitating further refinements in the production process to enhance performance and prevent premature failures. The novel warm peening process offers dual advantages. Firstly, it promises to boost the overall efficiency of the process chain in terms of energy consumption, resource utilization, and time savings. Secondly, it holds the potential to significantly enhance the mechanical properties of manufactured parts, particularly their fatigue resistance, through shot peening at elevated temperatures. This technique is recognized for its capacity to augment cyclic residual stress stability, fatigue strength, and, consequently, the longevity of critical components. The ShotTempering project represents a pioneering endeavor poised to revolutionize the manufacturing landscape, catering to the evolving demands of the transport sector while contributing to sustainability and energy efficiency goals.

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# Public Summary

Deliverable 2.1 of the ShotTempering project, developed in the frame of the RFCS program, aims at the description of the main steps followed throughout the selection and manufacturing process of the three steels that are considered to reach the project goals.

Along the different sections of this Deliverable, the main aspects related to the selection, manufacturing process and supply of these steels to be studied during the project will be described.

# 1 Introduction

## 1.1 Rational of this deliverable

This Deliverable 2.1 of the ShotTempering project, provides a detailed explanation of the three selected steels and their manufacturing processes. It serves to justify the choices made in alignment with the technical requirements of the three studied Routes and the objectives of the project.

These three steel grades, 27MnCr5 – 42CrMo4 – C55, to be studied in the subsequent project work packages (WP3, WP4, WP5, and WP6) were produced at Sidenor's facilities under the supply conditions agreed upon by the consortium.

<u>Attainment of the objectives and explanation of deviations</u>

All of the objectives of this Deliverable 2.1 have been full filled.

# 2 Selection of steel grades

Three specific steel grades were selected for the project, each corresponding to one of the manufacturing routes under study. These grades were chosen based on an optimization of mechanical properties, aligning with the conditions of each production process. This selection provides a basis for evaluating and comparing the steels' performance under targeted operational conditions, ensuring alignment with the ShotTempering objectives for durability and efficiency.

## 2.1 Route 1 – Steel for case hardening

For Route 1, focused on case hardening, the steel grade 27MnCr5 was selected as it is one of the most commonly used materials for gear manufacturing. Widely utilized by end-users in the industry, including CRF, this grade is known for its reliable performance in achieving high surface hardness and wear resistance, critical for gears subjected to high loads and dynamic operating conditions.

27MnCr5 steel with manganese and chromium as key alloying elements, provides improved hardenability and excellent mechanical properties. After carburizing, it achieves a hard surface while maintaining a tough, ductile core, critical for resisting surface fatigue and impact stresses. In this project, 27MnCr5 will be used to produce a gear demonstrator, showcasing its proven capabilities and suitability for demanding applications in mechanical transmission systems.

As agreed with CRF, this steel grade will be supplied as 70 mm diameter bars in an annealed condition.

## 2.2 Route 2 – Conventional hardening

For Route 2, focused on conventional quenching and tempering, the steel grade 42CrMo4 was selected as one of the most widely used materials for components requiring high strength and toughness. This grade is commonly employed in the manufacturing of torsion bars, shafts, and other critical mechanical parts due to its excellent balance of mechanical properties and its reliability under dynamic loading conditions.

After quenching and tempering, 42CrMo4 steel grade exhibits high tensile strength, good ductility, and resistance to fatigue, making it ideal for parts subjected to torsional stress. In this project, 42CrMo4 will be used to produce a torsion bar demonstrator.

As agreed with KIT and CRF, this steel grade will be supplied as 60 mm diameter bars in as-rolled condition.

## 2.3 Route 3 – Surface induction hardening

For Route 3, focused on induction hardening, the steel grade C55 was selected due to its suitability for achieving a hard, wear-resistant surface combined with a relatively tough core. C55 is a medium-carbon steel commonly used for components like shafts, axles, and other parts that require surface hardness while maintaining core toughness. Its carbon content allows for effective hardening in the induction process, forming a hardened layer that resists wear and fatigue without compromising the component's internal ductility.

As agreed with KIT and CRF, this steel grade will be supplied as 60 mm diameter bars in as-rolled condition.

# 3 Steel manufacturing process

The three steels considered in this project have been manufactured following the Sidenor manufacturing process. The main steps of this industrial procedure are: melting of the scrap in an EAF, secondary metallurgy, continuous casting into square billets and hot rolling into bars.

The selection of the appropriate process parameters is a critical aspect to guarantee the correct manufacturing of the steel. This is the reason why the chosen values are considered as know-how of Sidenor. Bearing this in mind, no details will be provided regarding this aspect.

Below, more information regarding the different steel manufacturing steps is given.

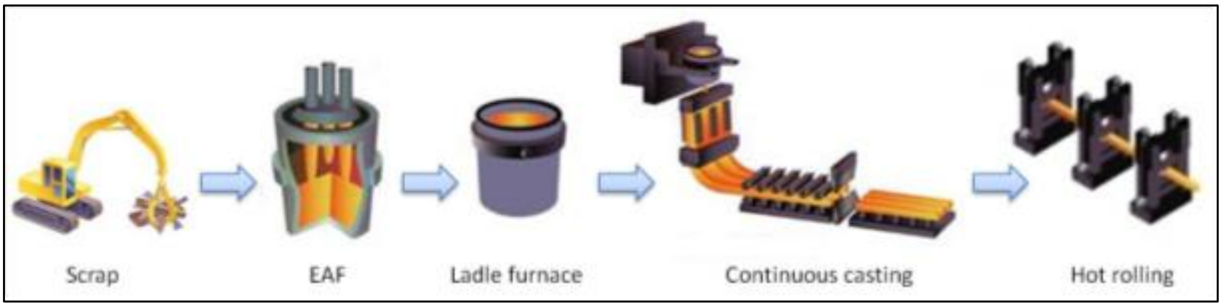


**Figure 1: Steel manufacturing process at Sidenor.**

## 3.1 Scrap selection

All the steel grades manufactured at Sidenor are produced from scrap. The scrap mix is carefully picked out considering the composition of the steel grade to be produced. This scrap selection has a special influence on the content of tramp elements.

**Figure 2: Scrap ready to be fed to the EAF.**

## 3.2 Electric arc furnace

The primary objective of the EAF is to melt the scrap. Additionally, a secondary objective of the EAF process is to ensure that the phosphorus content remains sufficiently low to prevent any reduction in the steel's toughness and elongation due to the presence of this element.

The main steps which take place in the EAF are: charging and melting of the scrap, and tapping to the ladle furnace where the secondary metallurgy is carried out.

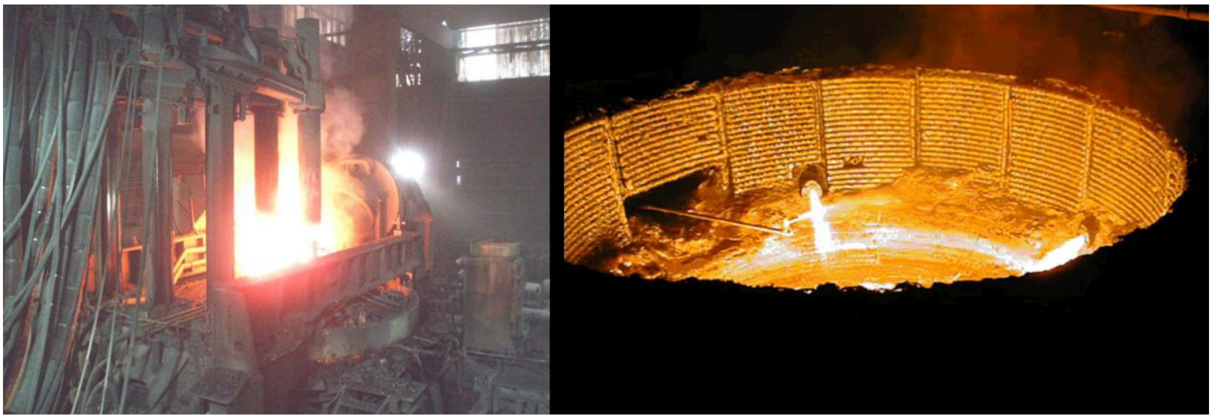

**Figure 3: Electric Arc Furnace**

## 3.3 Secondary metallurgy

This set of operations is developed in the ladle furnace. The main objectives of this step are the achievement of the desired chemical composition and to reach the optimal temperature to perform the casting.

While the liquid steel stays in the ladle furnace, it must be under continuous stirring in order to improve the contact with the slag. Thus, the decantation of inclusions is favoured, and the steel cleanliness is consequently enhanced.

The secondary metallurgy consists in three different steps:

- *Step 1: Refining*. During this phase, the steel is heated until reaching the required temperature to keep it in liquid state. In the refining, a rough adjustment of the chemical composition is carried out by adding C and some ferroalloys such as FeCr, FeMn… Besides, the steel S and O content is diminished through desulphuration and deoxidation processes.
- *Step 2: Vacuum degassing.* This operation is critical to attain the required cleanliness in the steel. Through a vacuum process, the steel dehydrogenation and denitrogenation phenomena take place. Furthermore, this vacuum helps the steel desulphurization started in the refining step.
- *Step 3: Final adjustment of the chemical composition.* Finally, in the last stage of the secondary metallurgy, the chemical composition of elements such as C, S, Al or Ti is fine-tuned adding wires in which the cited elements are content. Additionally, the temperature is also regulated in order to ensure that the continuous casting is carried out under the most suitable conditions.

## 3.4 Continuous casting

In the continuous casting the liquid steel is poured into a water cooled bottomless mold. The transversal section of this mold has the geometric shape of the semiproduct to be manufactured, in this case square billets with a section of 240x240 mm2.

The electromagnetic stirring carried out throughout this operation has a key role in the achievement of high quality steels, as it helps improve the steel homogeneity.

Other parameter that must be carefully chosen before the continuous casting is the casting speed, given that if the correct speed is not utilized, the likelihood of appearance of surface cracks remarkably increases.

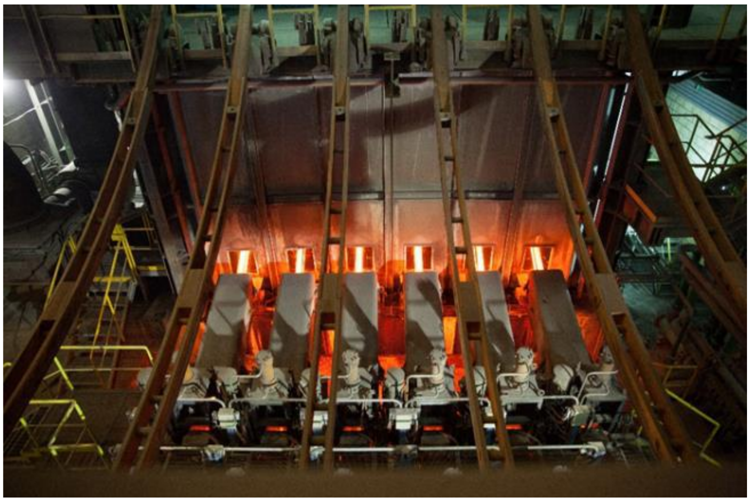

**Figure 4: Continuous casting machine.**

## 3.5 Hot rolling

In this process, the square billet formed in the continuous casting is hot rolled into bars. The rolled bars to be employed in the project have a diameter of 70mm for Route 1, 27MnCr5, and 60 mm for Route 2, 42CrMo4, and Route 3, C55.

It is well known that, to reach a good homogeneity of the steel properties, the rolling reduction ratio (the relationship between the section of the initial billet and the section of the rolled bar) must be at least 4-5. In this case, with the bars of maximum diameter 70 mm, the attained rolling reduction ratio is 14, so it can be stated that it is high enough to assure a good homogeneity level.

Considering that if an inadequate rolling temperature is used, many important problems may appear during the hot rolling, this temperature must be carefully selected for each of the considered steel variants.

## 3.6 Heat treatment

Heat treatment was applied only for the Route 1, where isothermal annealing was used to optimize the properties of the 27MnCr5 steel, selected for carburizing applications.

Isothermal annealing improves machinability by transforming the initial microstructure, typically composed of ferrite and coarse pearlite, into a finer and more uniform pearlitic structure, facilitating machining and reducing tool wear. It also relieves residual stresses generated during previous processes, such as rolling, thereby minimizing the risk of deformation or cracking during machining or subsequent heat treatments. Furthermore, this treatment prepares the steel for carburizing by stabilizing its microstructure, ensuring uniform carbon diffusion on the surface and enabling the desired properties to be achieved after hardening. This process is essential to ensure the steel meets the mechanical and performance requirements for its final application as a gear demonstrator.

## 3.7 Material supply

Once manufactured, the bars of each of the considered steel variants were carefully identified (Figure 5) to avoid any undesired materials mix.

**Figure 5: Detail of the bars identification.**

Finally, after the bars identification, the amount of material required to carry out all the tests specified in the project proposal was sent to each of the partners.

# 4 Final considerations

This deliverable has outlined the selected materials and manufacturing processes for the three steel grades used in the project, each tailored to the specific requirements of the production routes and demonstrators.

- Route 1 (case hardening), 27MnCr5 → gear demonstrator.
- Route 2 (quenching and tempering), 42CrMo4 → torsion bar demonstrator.
- Route 3 (induction hardening), C55.

In summary, the chosen materials and processes meet the project’s performance requirements, providing a strong foundation for the next stages.

# 5 Acknowledgements and disclaimer

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|---|---|---|
| 1 | I2M | I2M UNTERNEHMENSENTWICKLUNG GMBH |
| 2 | KIT | KARLSRUHER INSTITUT FUER TECHNOLOGIE |
| 3 | SIDENOR R&D | SIDENOR INVESTIGACION Y DESARROLLOSA |
| 4 | CRF | CENTRO RICERCHE FIAT SCPA |
| 5 | STRESSTECH | STRESSTECH GMBH |

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# Abbreviations and Definitions

| Term | Definition |
|---|---|
| **EAF** | **Electric Arc Furnace** |
| **EV** | **Electric Vehicle** |
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