ES3A8 DESIGN FOR MANUFACTURE ASSIGNMENT

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5th February 2018

1. **<u>Boothroyd Design for assembly task</u>**

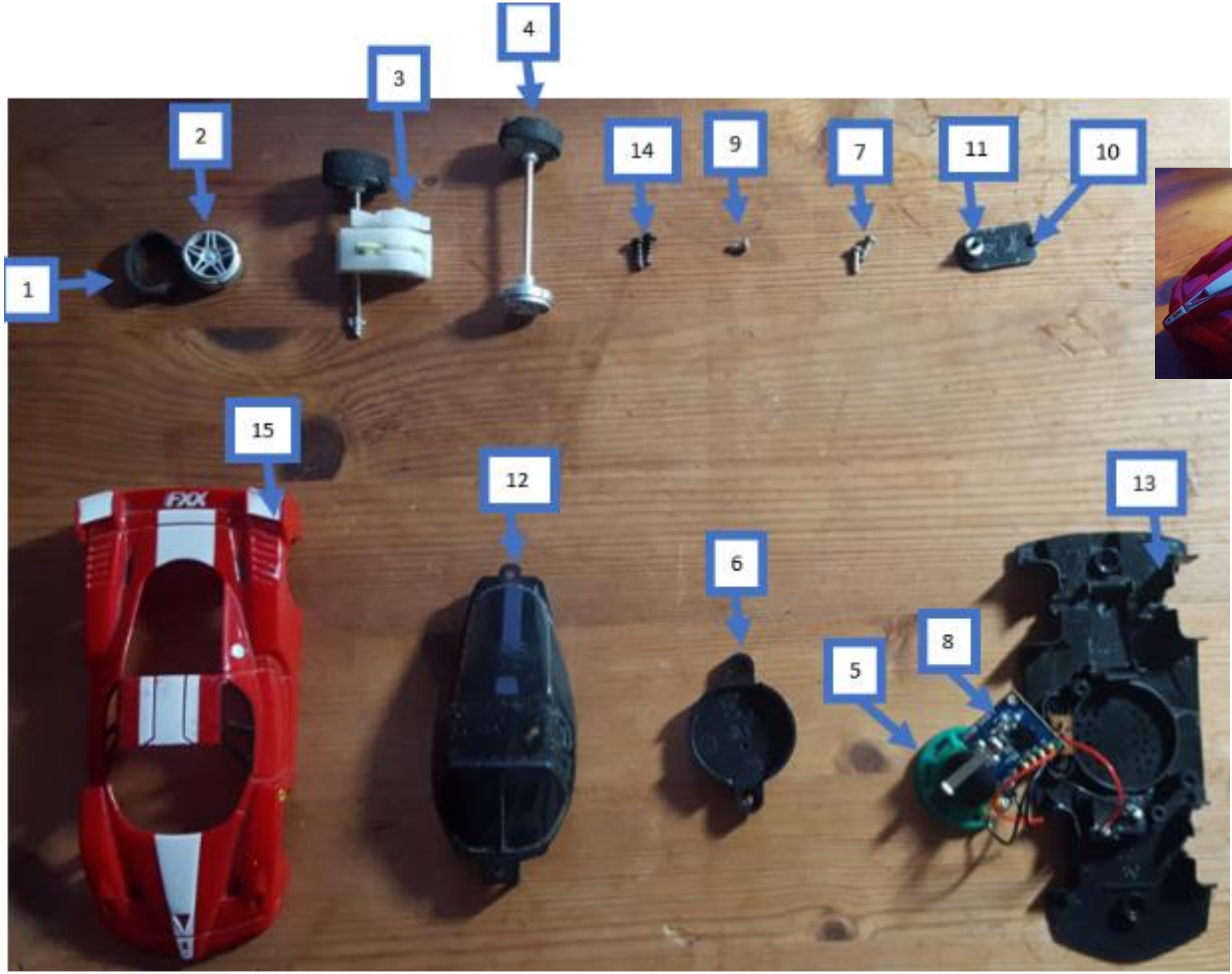


Figure 1 – Fully assembled car (above) and disassembled toy car (left). Numbers correspond to the part number in the first Boothroyd table

	Boothroyd Manual Process									
	Ferrari FXX toy									
Part Number	Operation/ Item	Description	Number of Items	Handling Code	Handling time (s) per item	Insertion Code	Insertion Time (s) per item	Essential? Yes/No	Total Time (s)	Cumulative Time (s)
1	Tyre	Rubbery material to enable forwards motion otherwise the car would not travel forward. Can deform plastically to fit onto the alloys	4	01	1.43	34	6	Yes	29.72 (Per item: 7.43)	29.72
2	(Plastic) Alloy wheel	Screws onto axle	4	11	1.8	38	6	No	31.2 (Per item: 7.8)	60.92
3	Wind up motor with rear axle	Click fits into position on floor	1	30	1.95	31	5	Yes	6.95	67.87
4	Front Axle	Fits into position on floor	1	00	1.13	00	1.5	Yes	2.63	70.5
5	Speaker	Fits into slot	1	10	1.5	30	2	Yes	3.5	74

6	Speaker Cover	Fits on top of the speaker	1	31	1.95	06	5.5	No	7.45	81.45
7	Long Silver Screws	Holds speaker cover onto floor	2	16	2.57	39	8	No	21.14 (Per item: 10.57)	102.59
8	Circuit board	Places on top of speaker cover	1	30	1.95	06	5.5	Yes	7.45	110.04
9	Short Silver Screw	Holds electronic chipboard to speaker Obstructed by wires	1	17	3.06	49	10.5	No	13.56	123.6
10	Battery cover	Alignment on floor	1	31	1.95	02	2.5	Yes	4.45	128.05
11	Battery screw	Screws to hold battery	1	16	2.57	39	8	No	10.57	138.62
12	Inner body	For windows and guides into floor	1	31	1.95	41	7.5	No	9.45	148.07
13	Floor	Main body is placed on this	1	30	1.95	06	5.5	Yes	7.45	155.52
14	Black Screws	Holding body to floor	2	16	2.57	39	8	No	21.14 (Per item: 10.57)	176.66
15	Main Body	Everything is attached onto this - snap fit	1	30	1.95	30	2	Yes	3.95	180.61

Initial Assembly Efficiency -

$$E = N_{min} \times \frac{t_a}{t_{tot}}$$

$$N_{min} = 11$$

$$t_a = 3\ s$$

$$t_{tot} = 180.61\ s$$

$$E = 0.18\ (3dp) \approx 18\%$$

This is an ineffective design for assembly, with an assembly efficiency of 18% a redesign is warranted; with the potential for cost savings being made as a result of alterations.

A redesign to make the Ferrari more efficient would involve the following improvements to the design for assembly –

- Have all alloys attached on the axles (removes need for 2)
- Integrate speaker into the speaker cover (removes need for 6) and makes the cover a part that is secured immediately with the press fit of the speaker – removes need for screws too (7)
- Integrate the main body and inner body together - can paint the colour of the windows on the main body instead
- Convert screwing operations to snap fit operations
- Make the battery cover a press fit – removes need for screws (11)

	Boothroyd Manual Process Reworked Ferrari FXX toy									
Part Number	**Operation/ Item**	**Description**	**Number of Items**	**Handling Code**	**Handling time (s) per item**	**Insertion Code**	**Insertion Time (s) per item**	**Essential? Yes/No**	**Total Time (s)**	**Cumulative Time (s)**
1	Tyre	Rubbery material to enable forwards motion. Can deform plastically to fit onto the alloys but placement is difficult	4	01	1.43	34	6	Yes	29.72 (Per item: 7.43)	29.72
2	Wind up motor with rear axle and alloys already attached	Click fits into position on floor	1	30	1.95	31	5	Yes	6.95	36.67
3	Front Axle with alloys already attached	Fits into position on floor	1	00	1.13	00	1.5	Yes	2.63	39.3
4	Speaker and Speaker Cover	Snap Fits on top of the speaker	1	31	1.95	30	2	Yes	3.95	43.25
5	Circuit board	Press fits on top of speaker cover	1	30	1.95	31	5	Yes	6.95	50.2

6	Press fit Battery cover	Alignment on floor	1	31	1.95	30	2	Yes	3.95	54.15
7	Floor	Electronic circuit boards and	1	30	1.95	06	5.5	Yes	7.45	61.6
8	Body with integrated inner body	Everything snap fitted in this	1	30	1.95	30	2	Yes	3.95	65.55

Assembly Efficiency for the redesigned car –

$$E = N_{min} \times \frac{t_a}{t_{tot}}$$

$$N_{min} = 11$$

$$t_a = 3\ s$$

$$t_{tot} = 65.55\ s$$

$$E = 0.50\ (3dp) \approx 50\%$$

The rework has improved the assembly efficiency by 32%!

Application to costs of the design for assembly

Original (18% efficiency, 180.61 second assembly time)

$$Minimum\ wage\ in\ the\ UK\ (25+)^{1} = £7.50$$

$$Cars\ produced\ in\ an\ hour\ per\ person\ \approx 20$$

$$Price\ per\ car\ (new) \approx £5$$

$$Net\ profit\ per\ hour = £100$$

$$Profit\ after\ wages\ paid = £92.50$$

Reworked (50% efficiency, 65.55 second assembly time)

$$Minimum\ wage\ in\ the\ UK\ (25+) = £7.50$$

$$Cars\ produced\ in\ an\ hour\ per\ person\ \approx 55$$

$$Price\ per\ car\ (new) \approx £5$$

$$Net\ profit\ per\ hour = £275$$

$$Profit\ after\ wages\ paid = £267.50$$

Hence after the rework, this saves an extra £175 per hour (with an 175% increase in profit with these numbers). This is a promising cost saving, however, the point in the life cycle of the toy must be considered to ensure the rework would be profitable - with this calculation not considering the cost of overheads. For instance, if tooling has already been generated and the cost of redesign outweighs the additional revenue from the efficiencies developed in the design, this will lead to a manufacturer of these toys to retain the existing process. Hence, this full redesign would have to be evaluated to ensure its economic viability, with a project earlier in its design process more likely to reap the rewards of efficient design for manufacture.

[1] (GOV.UK, n.d.)

2.

From the CCT diagrams Steel TRX2013A (Steel A) has a smaller martensitic region as opposed to Steel TRX2013B (Steel B). Thus, from initial observations to attain a fully hardened steel according to the CCT's Steel B has a greater hardenability than Steel A, with this occurring at a lower cooling rate; therefore, requiring less of a cooling effort with a coolant, further leading to a faster cooling time to reach a 100% fully hardened steel (martensitic structure).

The use of a coolant of H= 0.3 is used to prevent distortion and will allow heat to be removed from the surface of the bar to the outside environment, hence the bar cools only as quickly as heat can conduct from the centre to the surface. As the bar is not a consistent shape, different primitives will cool at different rates, therefore, the use of equivalent bar diameters (EBD) should be used.

The EBD was worked out by splitting the bar into 3 primitives. The first one being the cube (marked 1), followed by the trapezium prism (2) and the smaller central cuboid (3). The modulus is then derived by initially calculating the volume of the shape and surface area of the cooled surfaces – with the number of surfaces available to conduct heat away being 5 or 4 faces depending on which modulus is being calculated (5 faces for the cube as the top wall is also in contact with the mould wall, and 4 for the remaining primitives). See figure 2 for the application to the bar.

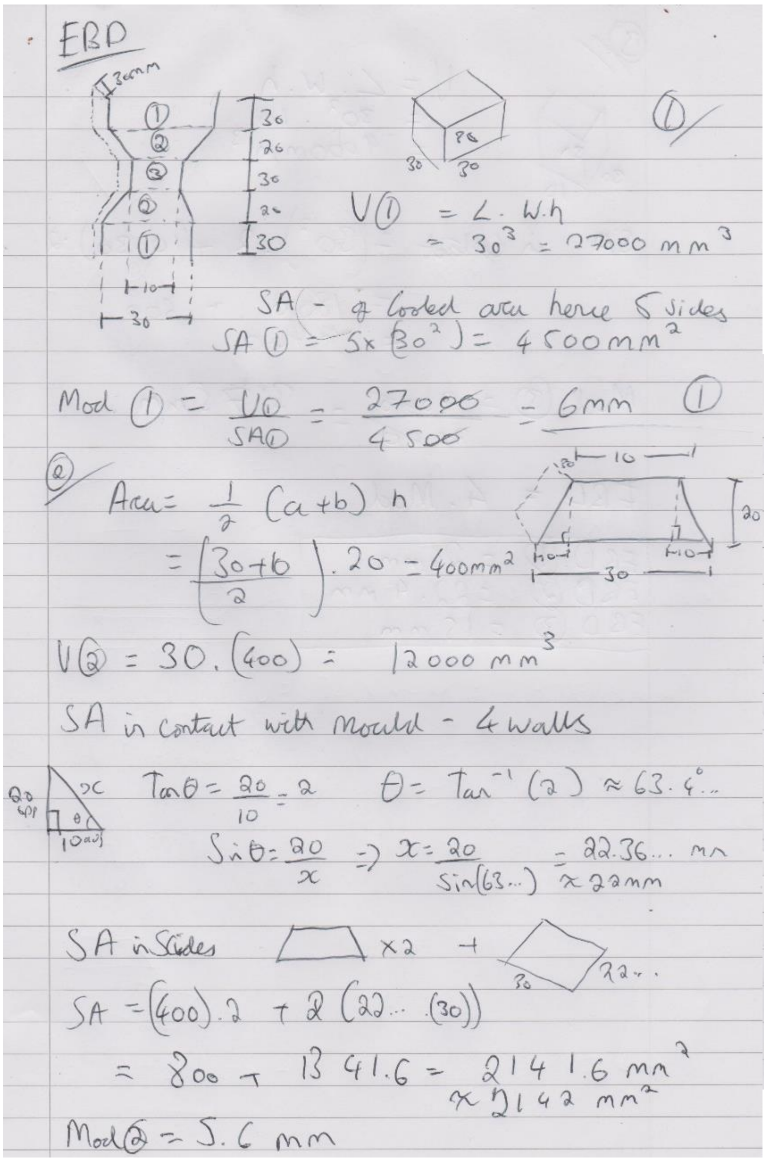
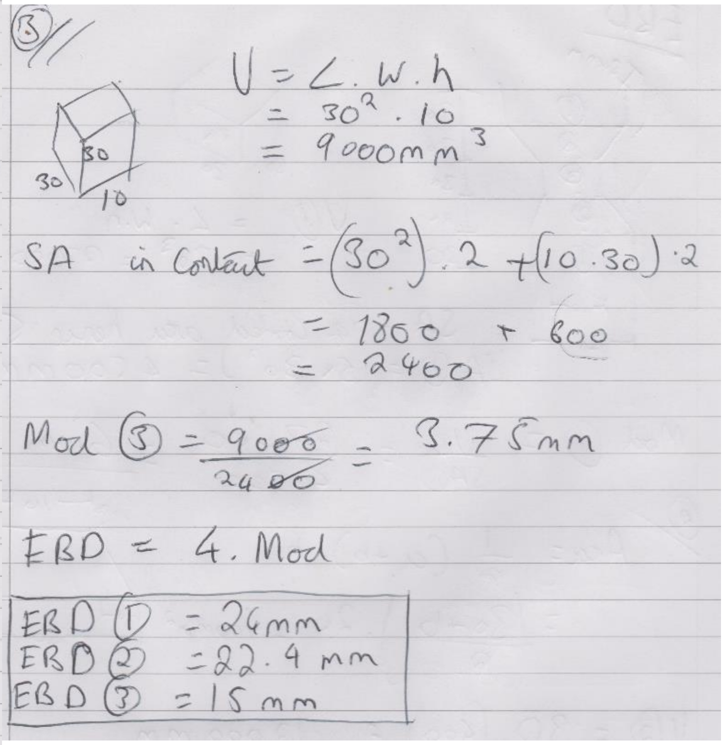


Figure 2 – Calculating the EBD of the company's bar



By multiplying the modulus by 4, the Equivalent Bar diameter is found (from dividing the area of a circular bar by its surface area this factor is found). It is important for the company to consider Chvorinov's Rule (Hughes, 2017) when this information is found:

$$T_s = c(\frac{V}{A})^n$$

Where:

T_s = Solidification time

c = Mould Constant

$\frac{V}{A}$ = Modulus

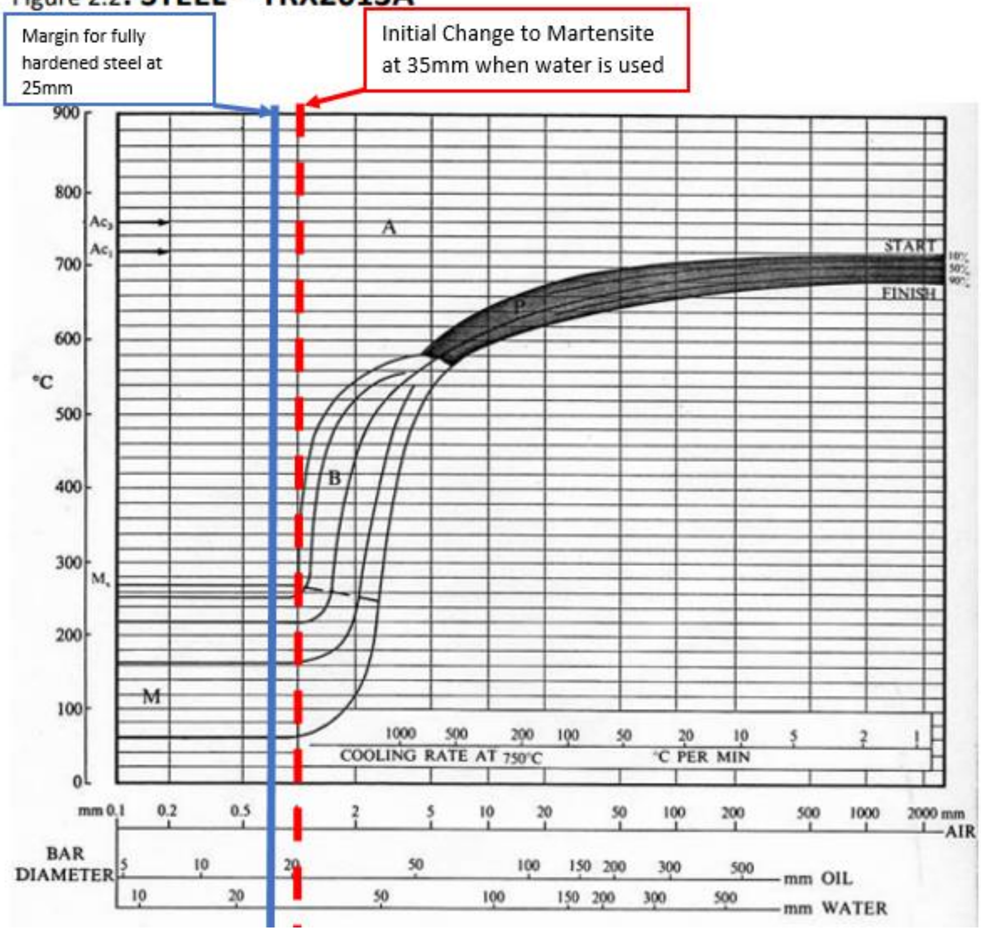
n = Constant

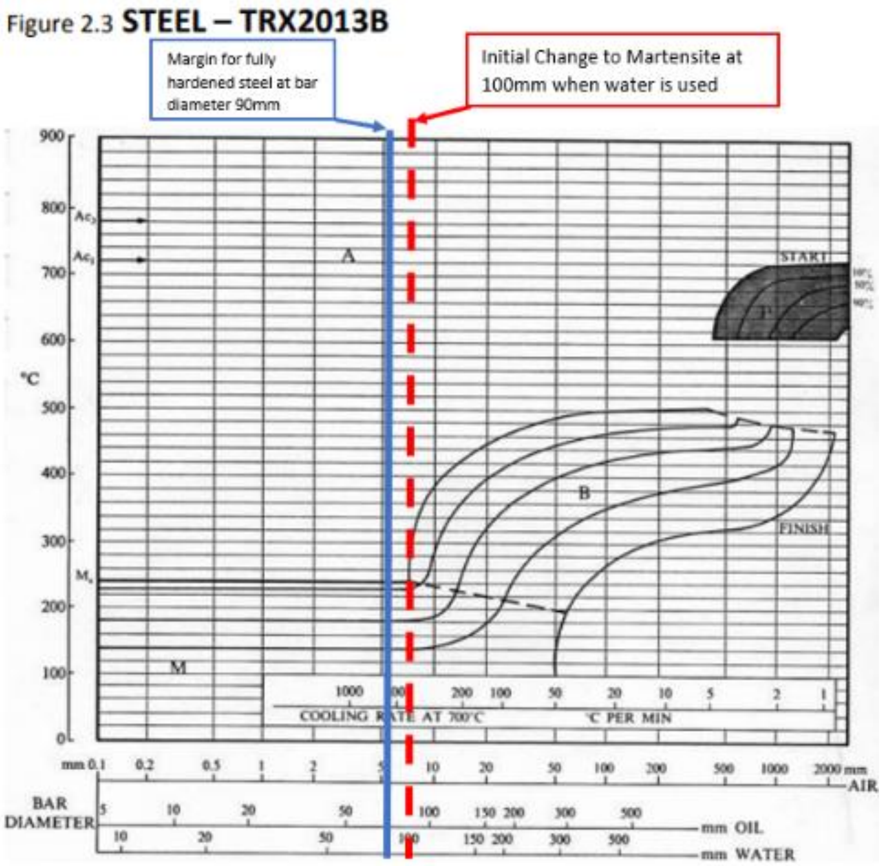
Thus, for the company, this rule highlights the proportionality between modulus and solidification time ($T_s \propto \frac{V}{A}$), therefore a company can use the modulus as a gauge to work out which parts take longer to cool and form a fully hardened structure than others.

From the EBD calculated it is clear that the cuboid takes the longest time to cool and form a fully hardened structure (with the highest EBD of 24mm), followed by the trapezium (22.4mm) and then followed by the smallest part the inner cuboid (15mm). The company must take these into consideration when deciding which steel to use to create the fully hardened component.

Having worked out the equivalent bar diameters, these can be compared to the ideal critical bar diameters from the CCT diagrams. By ascertaining when the steel is in its martensitic stage and by providing a margin to find the largest bar to form a fully martensitic steel, an ideal bar diameter can be ascertained.

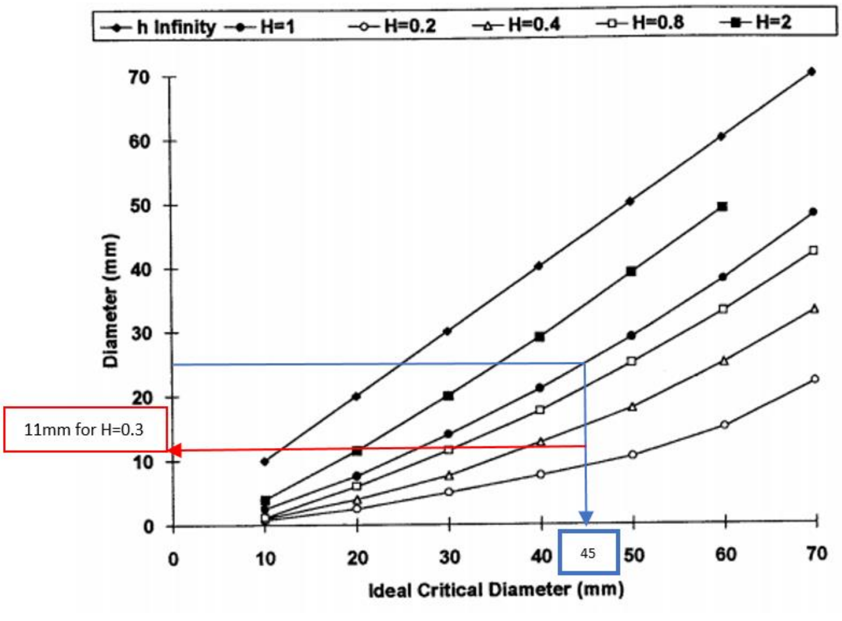
Figure 2.2: **STEEL – TRX2013A**



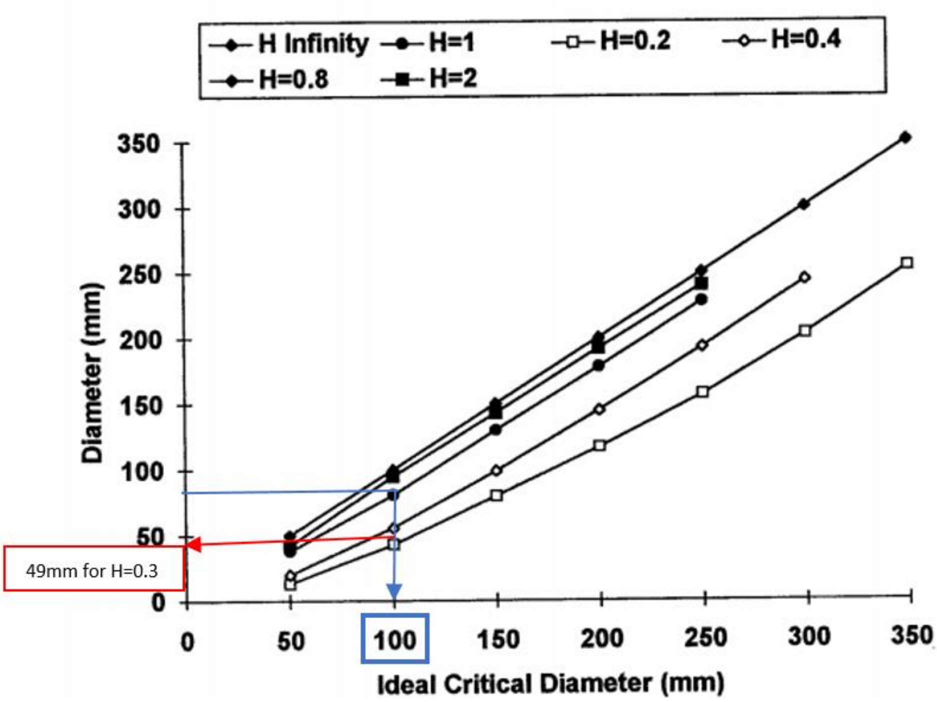


As already highlighted, from the CCT diagrams, martensitic growth in steel starts earlier in Steel B than Steel B, with Steel A fully hardened ideal bar size (with a margin) at approximately 25mm and Steel B at 90mm.

These values will now be used to work out the minimum bar diameter for the steel to harden and cool. From the coolant conversion charts the Ideal Critical diameter can be worked out using H=1 (the coolant value for water taken from the CCT diagram). From this the minimum bar diameter can be calculated by using a coolant with an H value of 0.3 (this being the midpoint of H = 0.2 and H = 0.4) and reading from the Ideal critical diameter. For A:



For B:



From these coolant conversion charts, the minimum bar diameter for Steel A to be a fully formed martensite steel is 11mm and for Steel B is 49mm. These must be compared by the company to the equivalent bar diameters. By using the part with the largest EBD (hence the cube with an EBD of 24mm) Steel B is above this threshold and will fully harden. Consequently, all the other parts to the bar will harden too. On the other hand, Steel A with a bar diameter of 11mm will mean that none of the components to the bar will fully harden and cannot be used for this process in its current state despite the Steel TRX2013A being more cost effective than TRX2013B. To make the most of his cost-effective Steel, Steel A would require a different coolant to achieve a fully hardened component, or alternatively, a redesign ensuring that the bars modulus does not exceed 11mm would allow Steel A to fully harden with the current constraints.

Overall, I would suggest to the company to use Steel TRX2013B over TRX2013A despite the cost savings. This is due to the fact that it is the only steel that allows full martensite to develop with the current constraints of bar size and coolants. It also has a larger margin for martensite to develop and requires a much lower cooling rate, hence, for the company to ensure the quality of its hardened steel, TRX2013B should be used.

Bibliography

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