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ESTABLISHMENT OF RELIABLE RELATIVE PRICE PREDICTIONS FOR HIGH-STRENGTH STEEL MEMBERS

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Abstract

In recent years, significant production improvements have been observed in the field of steel structures allowing for a constant increase in the yield strength and consequently for a reduction in the weight of structures. However, considering the required production techniques for high-strength steels, which are sometimes more demanding in terms of energy as well as more demanding in terms of alloy content, the manufacturing cost generally increases with the yield strength. Accordingly, designers and engineers are sometimes reluctant to consider higher steel grades as they do not know in which cases their use presents an economic benefit. Evaluating reliable relative prices for higher grades is seen as a necessity to realise a prospective study and prove their economic benefit but, looking to the literature, only a few publications address this topic. Thus, this article aims to establish relative price-strength relationships for different section typologies to help practitioners in choosing cost-effective steel grades for their applications. These investigations are based on previously available producer price lists to establish relative price intervals for existing and future emerging steel grades. The results of this article demonstrate the base price dependency and the key features which govern the relative prices and thus the economic benefit of such grades.

1. Introduction

According to the World Steel Association [1], steel demand is expected to increase by 20% until 2050 to meet the future needs of our growing population. Moreover, 20 years ago, only 25% of the 3500 steel grades in use today existed. The steel sector is in constant evolution and new emerging steel grades will continue to progressively appear in the world steel market. For instance, B235 and B355 grades have been substituted by the B500 grade for reinforcing steels and it could be expected that, in the future, S460 will share the construction market with S355 or even become the basic grade for structural steels.

In the meantime, technical knowledge concerning the design of high-strength steel members is deeply increasing by a lot of contributions in the literature thanks to national and international initiatives such as RFCS European projects [2–6]. The behaviour of these members when subjected

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to various loadings is evaluated through several scientific studies and new recommendations have been derived for standards. Besides, the new upcoming version of EN 1993-1-1 [7] covers steel grades up to S700, while the current EN 1993-1-1 [8] only covers grades up to S460 with a limited extension to higher steel grades in EN 1993-1-12 [9].

However, designers do not have a simple way to assess whether the use of such grade is economically justified and consequently their use is still limited in practice due to the low demand. Indeed, high-strength steel members are mainly produced for big construction projects with a huge need for materials and for which mild steel is no more adequate. For instance, S500 J0/M/ML grades are currently produced only for heavy hot-rolled sections in exceptional high-rise buildings requesting higher axial resistances for first-floor columns.

Despite an increase in the raw material cost with the yield strength, passing from a steel grade to a higher one results in a weight saving which may counterbalance the cost increase. To evaluate if the use of such high-strength steel grade presents an economic benefit, the establishment of reference and reliable relative price-strength relationships for existing and also future emerging steel grades appears to be essential.

Within the present article, a brief literature review related to the steel cost breakdown is firstly presented. Then, based on the outcome of this literature review, relative price-strength relationships are secondly derived for various steel products and compared with the literature. Finally, relative price-strength relationships are proposed for existing and future emerging steel grades.

2. Cost breakdown of steel structures

According to several cost functions [11–15] aiming at evaluating the manufacturing costs, the total cost can be divided into a series of cost components and can be generally written as:

$$C = C_{\mathrm{M}} + C_{\mathrm{B}} + C_{\mathrm{C}} + C_{\mathrm{S}} + C_{\mathrm{W}} + C_{\mathrm{P}} + C_{\mathrm{T}} + C_{\mathrm{E}} \quad (1)$$

with C_{M} being the material cost, C_{B} the blasting cost, C_{C} the cutting cost, C_{S} the sawing cost, C_{W} the welding cost, C_{P} the painting cost, C_{T} the transport cost and C_{E} the erection cost.

The use of high-strength steels enables to reduce:

1. The direct costs if the material saving allows compensating for the higher material cost of high-strength steels.
2. The indirect costs such as transport, painting, welding, erection and foundations thanks to the weight and surface reductions.

A literature review has been conducted to better understand how steel costs break down. An overview of cost breakdowns for steel structures available in the literature is shown in Fig. 1.

It appears that the percentages of the cost breakdown linked to fabrication and erection processes are roughly the same as the one associated with material cost. Scientifics and industrials both agree that the proportions of each main part are about 30 %.

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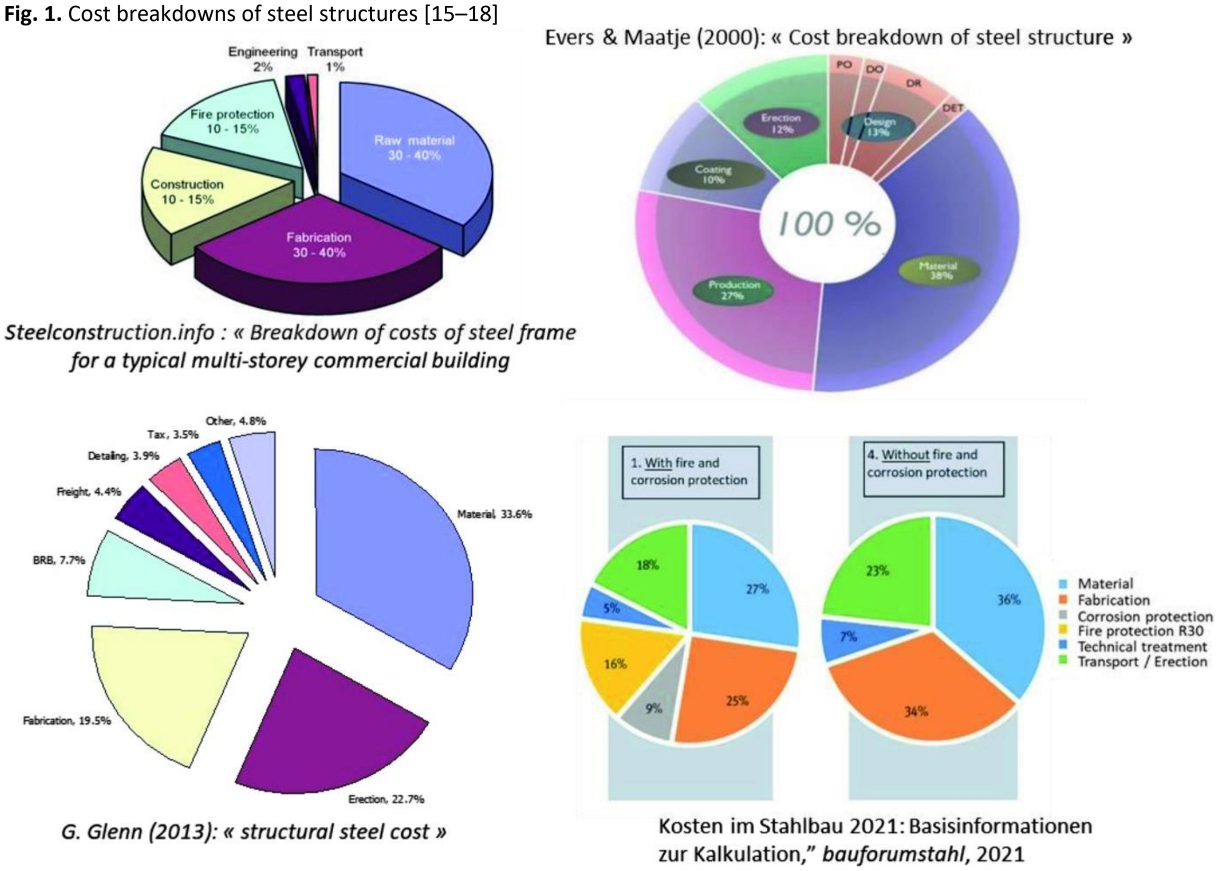
Within the present study, investigations on the impact of high-strength steels on costs only focus on the production stages, i.e., on modules A1 to A3 of the life cycle stages as defined in EN 15084 [19]. Indeed, higher yield strengths are obtained by a combination of alloys and production process; so, the production stages (A1 to A3) and especially the raw material components are deeply affected by the yield strength. However, given that high-strength steels lead to material savings, they also lead to a reduction of the cross-sectional area and thus a reduction in the primer coating, fire protection and transport costs. In conclusion, even higher yield strengths are likely to impact positively the transport and erection costs; it will be neglected given that it represents a low proportion in comparison with material and fabrication costs. Finally, only price list data will be detailed as these are the only values that the designers have in their possession when they must choose the most appropriate steel grade. Consequently, investigations in the framework of this article are focused on manufacturing costs from price lists.

Fig. 1. Cost breakdowns of steel structures [15–18]



3. Cost components and base price fluctuations

The manufacturing cost of steel elements is complex and fluctuating, as many factors can have an influence. Indeed, according to producer price lists, a price is often composed of a base price to which are added various extras. These extras come from dimensional differences (thickness-width, thickness-length, unitary weight), differences in grades and qualities, certificates (e. g., 3.1), and transport (rail or road). Other surcharges should also be considered such as those for quality tests (striction, coupon,

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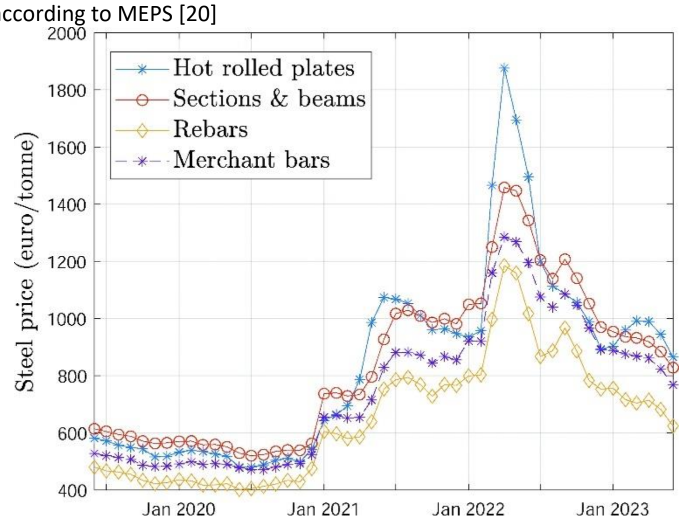
ultrasonic), possible shot blasting, cutting, sawing and painting. While extras seem to be constant in time according to the various collected price lists, base prices of steel members are highly time and space-dependent, and depending on their amplitude, the relative price between steel grades could be impacted. Fig. 2 illustrates the steel price evolutions at the European level according to the MEPS statistical website [20].

Fig.2. Europe steel prices according to MEPS [20]



Since 2002 and before 2021, except the financial crisis in 2008, base prices were relatively constant in a range between 500 and 700 €/t for hot-rolled plates and sections according to data from MEPS [20] and SteelBenchmarker [21]. However, as shown in Fig. 2, some recent historical events such as severe rises in production and energy prices, poor demand and the unforeseeable war-related disruptions in Ukraine contribute to the current high level of steel base prices given their impact on global supply chains. The price history explains that the prices are evolutive and can be sometimes at a very low level and sometimes at a very high level. This feature is fundamental and must be considered when computing the relative prices of high-strength steels.

The second key feature which impacts the base price amplitude is the provenance. The price lists considered in this article mainly come from Europe, the UK, and the USA.

Eventually, the last key feature is the ordered quantity. As for many goods, buying steel in bulk always offers a lower price per unit. However, the order quantity in steel structures is always high. Accordingly, the impact of the order quantity is not discussed in this article and no extra for the ordering of low quantities will be applied.

Therefore, in this article, relative prices are firstly established for hot-rolled coils and heavy plates for which high-strength steels (higher than 460 MPa) exist, and then, based on them, realistic relative price intervals are secondly established for hot-rolled sections to prospectively determine whether yield strengths higher than 500 MPa present an economic benefit knowing that, up to now, 500 MPa represents the highest steel grade available for such hot-rolled sections.

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4. Relative prices for already existing steel grades and comparison with the literature

High-strength steels, i.e., steels with a yield strength between 500 and 700 MPa, are already covered in EN 10149-2 [22] and EN 10025-6 [23]. The first deals with thermomechanically (TM) hot-rolled steels for cold forming, usually delivered as coils, while the second deals with quenched and tempered (QT) steel plates. In the report of the European RFCS project RUOSTE [5], authors compare two articles published by Johansson [24] and Stroetmann [25] which derive relative material prices for high-strength steel heavy plates. Although these two references are regularly cited when analysing the economic benefit of using high-strength steels ([26–31]), the two trends are significantly different. Indeed, in 2005, Johansson [24] assumes that the relative price trend follows the square root of the yield strength, while, in 2011, Stroetmann [25] provides lower relative values based on average prices from several producers in the German market. These relative prices are discussed in this section considering the already existing high-strength steel coils and plates.

4.1. TM HOT-ROLLED HIGH-STRENGTH STEELS FOR COLD FORMING ACCORDING TO EN 10149-2

This first cost analysis is based on a steel sheet order realised in March 2021. The product is a black sheet (without surface treatment) 1500 × 6000 × 6 mm in S355 J2+N and the cost breakdown was the following:

$$\text{Cost} = \underbrace{730€/\text{t}}_{\substack{\text{Base}\\\text{price}}} + \underbrace{\mathbf{50€/t}}_{\substack{\text{Grade}\\\text{extra}}} + \underbrace{16€/t}_{\substack{\text{Width}\\\text{extra}}} + \underbrace{25€/t}_{\substack{\text{Length}\\\text{extra}}} + \underbrace{25€/t}_{\substack{\text{Extra}\\\text{for}\\\text{certifi-}\\\text{cates}}} = \underbrace{846€/t}_{\text{Total cost}} \tag{2}$$

The different cost components expressed hereinabove have been confirmed by some mill's price lists. In the framework of this research, attention has been paid to grade extras as only the latter directly depends on the steel grade, thus other extras have been assumed as constant. Accordingly, deeper research has been conducted to establish a relative price–strength relationship. The online website Vosta Stahlhandel Gmbh [32] and other mill price lists (US Steel Kosice 2017 [33], Tata 2013–2015 [34, 35], Salzgitter [36], Voestalpine [37], Arvedi [38] and SSAB [39]) contain their respective grade extras for hot-rolled sheets/coils (Tab. 1). The linear interpolation is expressed in Eq. (3).

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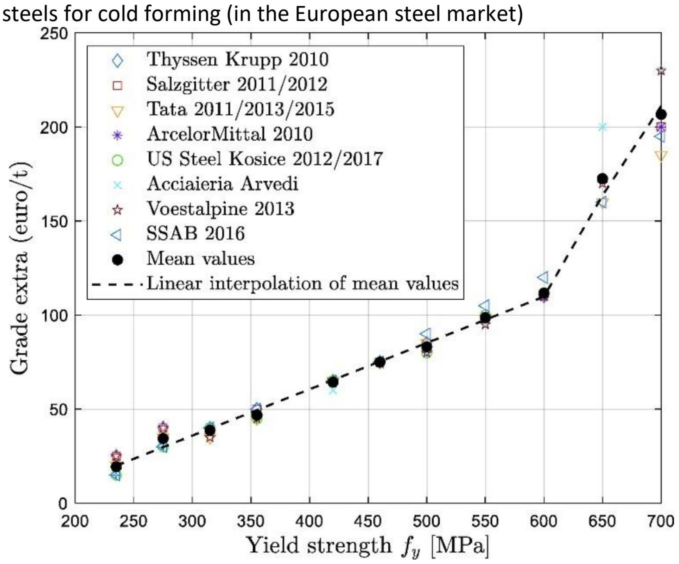
Table 1. Grade extras for TM steels for cold forming [€/t]

Steel specification	Thyssen Krupp (2010)	Salzgitter (2011–2012)	Tata (2011–2013–2015)	ArcelorMittal (2010)	US Steel Kosice (2012–2017)	Acciaieria Arvedi	Voestalpine (2013)	SSAB (2016)
S235 JR	16	16	10	5	5	5	10	15
S235 J2	25	25	20	15	15	15	25	15
S275 JR	21	21	20	15	15	20	20	20
S275 J2	-	40	35	30	30	30	40	30
S355 JR	-	45	40	35	35	35	40	40
S355 J2+N	59	59	55	**50**	**50**	**50**	-	60
S355 J2	59	55	50	45	45	45	50	50
S315 MC	40	40	35	40	40	40	35	40
S355 MC	50	50	45	45	45	45	45	50
S420 MC	65	65	65	65	65	60	65	65
S460 MC	75	75	75	75	75	75	75	75
S500 MC	85	85	85	80	80	80	80	90
S550 MC	98	98	98	100	100	95	95	105
S600 MC	110	110	–	110	–	110	110	120
S650 MC	–	–	160	–	–	200	170	160
S700 MC	–	200	185	200	–	230	230	195

Referring to the United States Steel Corporation [40] and ArcelorMittal USA [41], it appears that the American price lists for HSLA (high-strength low-alloy steels) with improved formability are in line with the European trend derived in Fig. 3.

$$\text{Extra}_{\text{grade}}(f_y) = \\ = \begin{cases} 0.2463 \cdot f_y - 37.937, & f_y \leq 600 \text{ MPa} \\ 0.95 \cdot f_y - 453.89, & f_y > 600 \text{ MPa} \end{cases} \quad (3)$$

Fig. 3. Grade extras for TM steels for cold forming (in the European steel market)



Based on Eq. (3) and considering the example treated in Eq. (2), relative prices between a given grade and S235 J2 can be computed as

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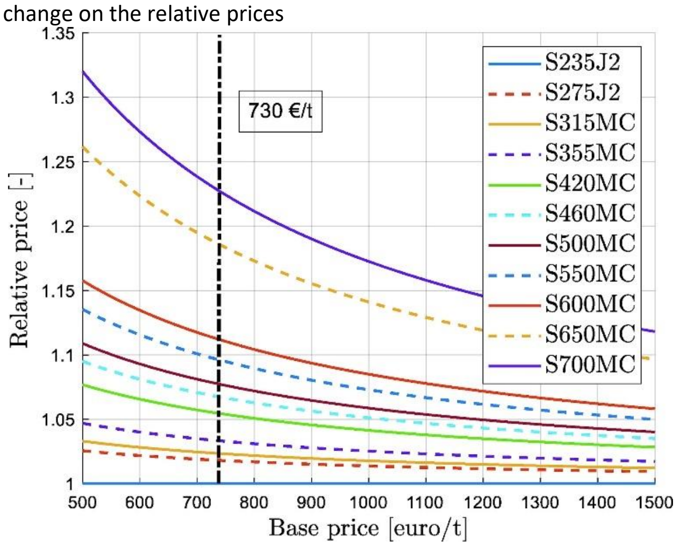
$$\frac{c_{\text{grade}}}{c_{\text{S235J2}}} = \frac{730\ €/\text{t} + \text{Extra}_{\text{grade}} + 16\ €/\text{t} + 25\ €/\text{t} + 25\ €/\text{t}}{730\ €/\text{t} + \text{Extra}_{\text{S235J2}} + 16\ €/\text{t} + 25\ €/\text{t} + 25\ €/\text{t}} \quad (4)$$

For the sake of comparison, S235 J2 is chosen as the reference steel because this is the grade chosen as reference by Stroetmann [25]. The following relative prices are then obtained considering the linear interpolation derived in Fig. 3: S235 J2=1.000, S355 J2=1.037, S315 MC=1.024, S355 MC=1.034, S420 MC=1.055, S460 MC=1.068, S500 MC=1.078, S550 MC=1.097, S600 MC=1.113, S650 MC=1.188 and S700 MC=1.229. Of course, these relative ratios are inherently dependent on the base price. A sensitivity study to establish the base price influence has been performed in MATLAB [42] and the results are graphically represented in Fig. 4. The higher the base price, the lower the relative prices of high-strength steel grades because grade extras are considered insensitive to base price changes as confirmed by the conducted literature review and several industrial exchanges. Indeed, the constancy of the grade extras can be explained by the fact that the alloying percentage is negligible in the steel composition. Besides, the similar values in Tab. 1 over time confirm that the competition between producers is only based on the base price. Therefore, it was assumed that only the base price is impacted by the steel market fluctuations.

Fig.4. Effect of a base price change on the relative prices



In addition, the relative prices tend to decrease when some size extras are applied because increasing the yield strength leads to a size reduction which may correspond to a lower size extra category. So, to get conservative relative prices, it has been decided to focus on grade extras by keeping the same cross section for both compared grades.

Figure 5 reports both literature values, respectively, proposed by Johansson [24] and Stroetmann [43] for plates, some values from Ruukki [44] and a Belgian supplier for TM hot-rolled coils, and three evolutions computed through the cost estimation proposed in the present article by considering three significantly different base price levels for hot-rolled coils: low level (500 €/t), intermediary level (750 €/t) and high-level (1000 €/t).

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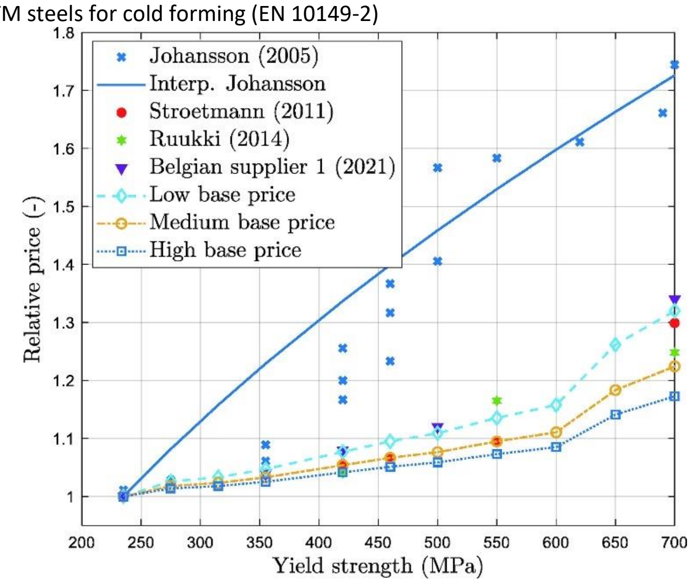
Fig.5. Relative prices for TM steels for cold forming (EN 10149-2)



As shown in Fig. 5, the established relative price relationships are validated by Stroetmann and the other collected values. Referring to a presentation by Stroetmann [45], it appears that the base price at the publication period (October 2010) was equal to 700 €/t; it explains why the 'medium base price' curve corresponding to a base price of 750 €/t is closer to the Stroetmann's relative prices. In addition, according to [44], Stroetmann's values are for TM steels for cold forming, so the product standard is the same as the one considered herein. In addition, according to the chemical compositions prescribed in EN 10149-2 [22], a boron ('B') alloying element is added to the steel composition for yield strengths higher than 600 MPa and the unitary price of this alloying element is relatively high [46, 47]. Thus, the use of this alloying element can explain why there is a sudden increase in the grade extra–yield strength relationship at 600 MPa. Eventually, in addition to the boron, molybdenum is also added to the chemical compositions for grades higher than 600 MPa for avoiding heat-affected zone softening in weld areas [48]. The second reason that can explain these increases is the requirements in terms of toughness. Indeed, for higher yield strengths, a much finer-grained microstructure is desirable to enhance low-temperature toughness performance [48]. The third reason coming out from exchanges with industries is associated with marketing strategies behind the selling of such high-strength steels.

4.2. FINE-GRAINED STRUCTURAL STEELS MADE TO EN 10025–6, WATER QUENCHED AND TEMPERED

The high-strength steel guide [49] expresses some cost breakdowns for steel plates ordered to compose flanges and webs of welded I-beams for hybrid girders. A cost breakdown is given for a 24300×1000×20 plate in S460 M, and details are reported here below.

$$\text{Cost} = \underbrace{850}_{\text{Base price}} + \underbrace{188}_{\text{Grade extra}} + \underbrace{162}_{\text{Alloy extra}} + \underbrace{15}_{\text{Width extra}} + \underbrace{28}_{\text{Length extra}} + \underbrace{24}_{\text{Cert. 3.1}} + \underbrace{28.8}_{\text{Blasting}} + \underbrace{21.56}_{\text{Transport}} = \underbrace{1317.36}_{\text{Total price}} \text{ €/t} \quad (5)$$

Heavy plates of yield strengths higher than 500 MPa only exist for fine-grained structural steels (QT steels – EN 10025-6). Referring to several Dillinger (2012 to 2016), Ilsenburger–Salzgitter (2011) price

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lists [50, 51], various grade extras are reported in Tab. 2. These extras depend on the thickness; an increase of +35 €/t has to be applied to reach the second thickness domain (up to 70 mm) and +85 €/t for thicknesses up to 100 mm. Indeed, the thicker the plate, the higher the alloying percentage to reach the expected yield strength and thus the higher the grade extra.

According to the consulted price lists, additional extras for alloy content upcharges/discounts must be added when evaluating the total cost as reported in Tab. 2.

Table 2. Grade extras for heavy plates [€/t]

Grade typology	Steel specification	Thickness domain	Extras	Alloy extra
Unalloyed structural steel made to EN 10025-2	S235 J2	≤ 195	26	–
	S355 J2	≤ 195	59	–
High-strength, fine-grained structural steels made to EN 10025-6, water quenched and tempered	S460 QL	≤ 40	288	36
	S500 QL	≤ 40	298	36
	S550 QL	≤ 40	311	39
	S620 QL	≤ 40	328	39
	S690 QL	≤ 40	346	39
	S890 QL	≤ 40	446	135
	S960 QL	≤ 40	481	135
	S1100 QL	≤ 40	551	175

In the same manner as for coils in Section 4.1, grade extras evolve linearly as a function of the yield strength, they can be computed as:

$$\mathrm{Extra}_{\mathrm{grade}}(f_y) = \\ = \begin{cases} 0.2516 \cdot f_y + 172.27, f_y \leq 620\ \mathrm{MPa} \\ 0.5 \cdot f_y + 1, f_y > 620\ \mathrm{MPa} \end{cases} \quad (6)$$

Considering the given example, the relative price can be conservatively expressed as

$$\frac{c_{\mathrm{grade}}}{c_{\mathrm{S235J2}}} = \frac{P_{\mathrm{base}} + \mathrm{Extra}_{\mathrm{grade}} + \mathrm{Extra}_{\mathrm{alloy}}}{P_{\mathrm{base}} + 26\,€/\mathrm{t} + 0\,€/\mathrm{t}} \quad (7)$$

As mentioned in Section 4, Johansson and Stroetmann gave some relative values for hot-rolled heavy plates which are under concern here. Thus, a comparison between the literature values and the ones based on Eq. (5) with various base prices has been performed as reported in Fig. 6.

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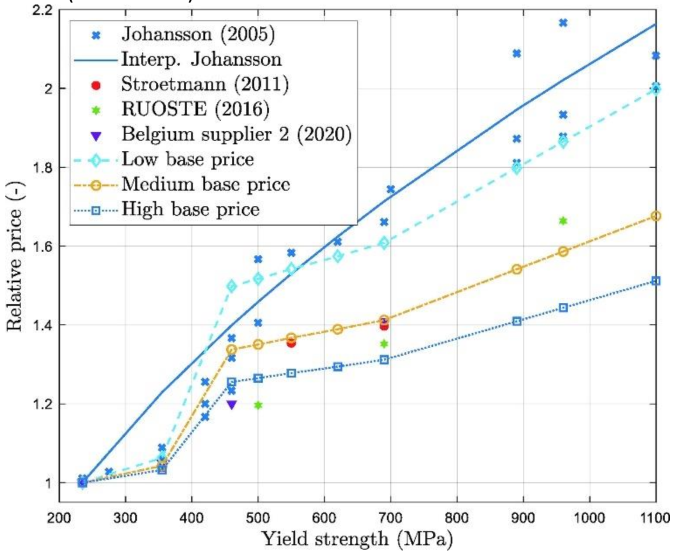
Fig.6. Relative prices for QT steels (EN 10025-6)



As shown in Fig. 6, the computed values for medium base price are still close to Stroetmann even for this steel category (QT steels) which confirms the consistency of the computed trends. In addition, the base price was low in 2005, probably around or even below the low base price (500 €/t). It explains why the "low base price" trend is closer to the interpolated values of Johansson. Regarding the scattered values of Johansson, there is also a change of slope at 620 MPa which confirms the relevant trend obtained.

Accordingly, both literature trends are validated but the Johansson's interpolation does not give good results correspondence for TM steels and especially this trend would be over-conservative in this period of high base prices. Based on these two comparisons, this study confirms that the differences in the literature relative prices can be explained by the production process improvement between 2005 and 2011 as stated in the RUOSTE project [5]. Indeed, thermomechanical treatment is nowadays preferred to reach high-strength properties for structural applications given its better welding performance; this production change has led to lower relative prices for such grades.

5. Establishment of relative prices for future emerging steel grade

For hot-rolled sections, the maximum yield strength marketed in Europe is 500 MPa (on special order since 2019), while 550 MPa (grade 80) is already available in the USA. The S550 grade is likely to appear in the medium term on the European market after the revision of EN 10025 (which takes place every 3 to 4 years). Similarly, as for the previous section typologies, the relative price investigations are based on a selected example, i.e., a HEA160 profile in S355JR. The estimation of the extra values is extracted from an ArcelorMittal price list.

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$$\text{Cost} = \underbrace{800}_{\text{Base price}} + \underbrace{15}_{\text{HEA vs HEB}} + \underbrace{50}_{\text{Profile Cat. 4 Vs Cat. 1}} + \underbrace{35}_{\text{Grade extra}} + \underbrace{15}_{\text{Length extra}} + \underbrace{25}_{\text{Cert. 3.1 and add. tests}} = \underbrace{940}_{\text{Total cost}} \text{€/t} \quad (8)$$

As expressed in Eq. (8), for hot-rolled sections, there are two types of extras associated with the geometry of the considered section: extras depending on the profile range (HEA, HEB, HD, IPE, …) and extras depending on the profile category within a range (HEA100, HEA120, HEA140, …). The considered reference values are extracted from several ArcelorMittal price lists of 2015, 2016, and 2017 [52] which were available online.

5.1. GRADE EXTRAS OF EXISTING SECTIONS FOR UNALLOYED AND TM PRODUCED STEELS

Each of ArcelorMittal price lists consulted for hot-rolled sections gives the same grade extras as reported in Tab. 3. Given that S500 M and S500 J0 appeared in the corresponding standards in 2019, there was no value available for these grades before.

Table 3. Grade extras from recent ArcelorMittal price lists [€/t]

Steel specification	ArcelorMittal price lists 2015, 2016 and 2017
S235 J0	BASE
S235 J2	20
S275 J0	BASE
S275 J2	20
S355 J0	40
S355 J2	50
S460 J0	80
S355 M/Histar 355	60
S460 M/Histar 460	100

As can be seen, the grade extra increases with the yield strength. This statement is correct for all the collected price lists in the European steel market except for British sections (according to Corus, Tata steel, and British sections [53-55]) as reported in Tab. 4.

Indeed, as can be seen in Tab. 4, the grade extra for S275 JR is unexpectedly higher than for S355 JR since 2013. This non-growing extra trend can be explained by the market share in the UK. In fact, according to an estimated market share in 2012 [56], steel corresponds to the most represented material in the building sector in the UK (70 % of the market share), while it represents only 20 % in the Benelux, 20 % in France or even 10 % in Germany. In addition, producers tend to push for the use of S355 rather than S235 to account for the recycling process and eventually leave such low mild steels.

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Besides, the S355 steel grade is the most used in the UK, while S235 is still preferred in other European countries [56].

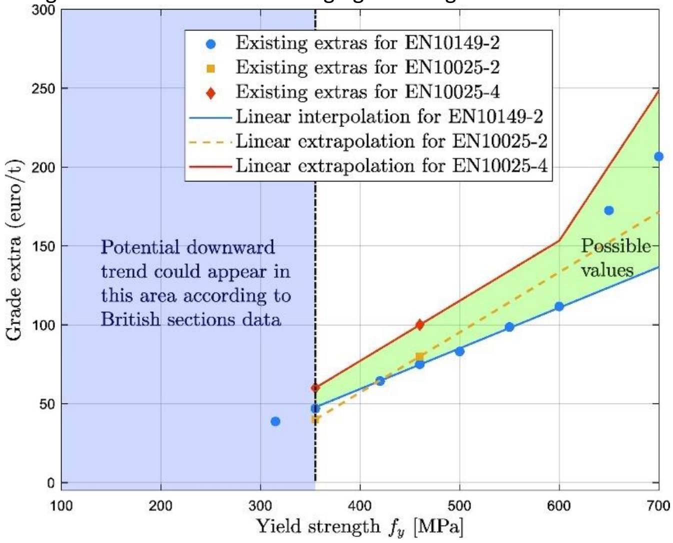
Table 4. Grade extras for British section (£/t)

Steel specification	Corus long products 2010	Tata steel sections 2013	British sections 2020
S275 JR	Basis	30	30
S275 J0	25	40	40
S275 J2	30	80	80
S355 JR	30	Basis	Basis
S355 J0	40	10	10
S355 J2	85	40	40
S355 K2	110	80	80

5.2. ESTIMATION OF GRADE EXTRAS FOR FUTURE EMERGING GRADES

At the University of Liège, investigations have been conducted to evaluate the economic benefit of using high-strength steels up to S700 for hot-rolled profiles as a prospective study [57]. Accordingly, although steel grades higher than S500 do not exist in the European steel market yet, some "realistic" values should be proposed to allow for this prospective study. Starting from Eq. (8), it is required to propose realistic extrapolations for the grade extras of steel grades higher than S460 (Fig. 7).

Fig.7. Determination of realistic grade extras for future emerging section grades



This area of possible values in Fig. 7 has been obtained by considering two different extrapolations, i.e., the upper boundary by assuming a bilinear extrapolation of the existing values for hot-rolled sections based on the slopes defined in Eq. (3) for TM steels for cold forming and the lower boundary by the linear extrapolation of the first slope up to S700 in a conservative approach. Several arguments can explain why similar values as for hot-rolled coils should be contemplated for sections, i.e.:

- As-rolled steel grade extra for S355 J0 is the same for both typologies (+40 €/t) and it should become the base grade for sections according to [56]. In addition, steels from EN 10025-2 reveal similar values for S355 J0/S355 MC and S460 J0/S460 MC (difference of 5 €/t).
- For thicker elements, the need for alloying elements increases; it is for this reason that a range has been considered but it appears that the grade extras are more sensitive to the production process than the chemical compositions. Besides, heavy plate price lists show an identical evolution for the 'MC' quality as for the 'M' quality [50]. As a reminder, both are produced via a thermomechanical process which requires less carbon and alloy contents for a better weldability than for QT steels [48]; thus, it makes sense to expect a similar trend for grade extras.
- According to a price list for hot-rolled coils, the grade extras for S355 MC and S460 MC were equal, respectively, to 60 and 95 €/t in 2009. These values are similar to the current ones for long products in S355 M and S460 M. Accordingly, as for TM hot-rolled coils, it is reasonable to assume that the grade extras for S355 M and S460 M will likely be decreased when new emerging steel grades, i. e., S500 M, S550 M and so on, will appear in the steel long product market.

Although chemical compositions differ between both section typologies, especially between steels from EN 10149-2 and EN 10025-4, the chemical composition only slightly affects grade extras as these extras are fixed by the competitive market. However, because of these differences and the dependence on base prices and section thickness, a domain of realistic values has been established for future emerging section grades. Accordingly, realistic grade extra ranges for future emerging steels can be proposed such as [50; 60] €/t for S355, [75; 100] €/t for S460, [85; 115] €/t for S500, [98; 134] €/t for S550, [112; 153] €/t for S600 and [137; 248] €/t for S700.

5.3. RELEVANT RANGES FOR RELATIVE PRICES

In addition to the variability of grade extras due to the chemical compositions, semi-finished products for sections are more likely to be produced in electrical furnaces (EAF production route), while coils are rather produced in basic oxygen furnaces (BOF production route). This feature directly affects the base price. Based on the previous grade extra intervals, a range of relative prices can also be established considering low and high base price values defined in Section 4.1 to account for the production route as represented in Fig. 8. The lower bound is obtained by considering the highest base price with the lowest grade extra, while the upper bound is conservatively obtained by considering the lowest base price with the highest grade extra.

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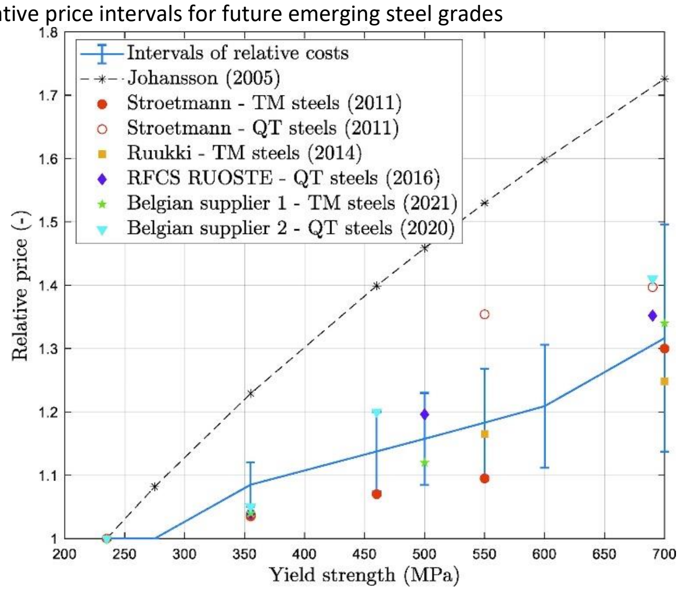
Fig.8. Establishment of relative price intervals for future emerging steel grades



As shown in Fig. 8, all collected data confirm the relative price ranges and illustrate the variability due to the production process and the base price fluctuations in time. The proposed conservative values for TM steels are 1.00 for S235, 1.05 for S355, 1.15 for S500, 1.20 for S600, and 1.30 for S700.

It is worth recalling that when establishing the above relative prices, it was assumed that the same profile was made of different grades of steel. However, in an actual design process, the use of steel with a higher yield strength often conducts in a reduction of the required cross section and so to a reduction of one or even several profile sizes so other extras (dimensions, blasting, painting, …) may also be positively impacted. In this manner, the established ranges are thus conservative.

According to the RUOSTE project [5], the same evolution as for plates is contemplated for cold-formed tubular sections. Therefore, the relative price ranges proposed here above may also be considered to study the economic benefit in using high-strength steels for tubular sections.

6. Conclusions

This article illustrates that high-strength steels undeniably lead to an increase in material costs. However, as explained earlier on cost breakdown, the material cost only represents 33 % of the total cost. Manufacturing costs should only be slightly affected by the yield strength increase given other costs (shot blasting, painting, transport, etc.) are generally positively affected by this yield strength increase because these steels lead to material savings and thus to a surface/weight reduction. In addition, this weight gain also compensates for the material cost increases, which in most cases leads to an economic benefit in using these steels. Finally, as demonstrated in this article, for certain types of sections, these steels are not yet commercialised or are only used when normal steel grades are no more sufficient in terms of resistance. It is likely that, when their economic benefit will be proven, the demand for them will increase. As steel is a primary material whose prices are governed by the supply and demand law, base prices will continue to fluctuate over time and it has been shown that, when the base prices of steel are high, the economic benefit in using these high-strength steels is higher because the impact of grade extras on the relative prices becomes neglectable.

This article gathers and proposes some grade extra–strength functions and relative price-strength relationships depending on the section typologies. In addition, it has been proven that the Johansson relationship seems to be no longer applicable today as new improved treatments like the thermomechanical process have been developed to reach higher resistance properties. Indeed, nowadays, thanks to the thermomechanical process, high-strength steels can be produced with a lower alloying content keeping excellent weldability for their structural applications even for thick products. As a perspective, further developments may be performed for different section typologies to provide some guidelines to practitioners to select the most appropriate steel grade based on the relative price–strength relationships established in this article.

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