GENERAL GUIDELINES FOR STELLITE® HARDFACING ONTO STEEL SUBSTRATES

Stellite® cobalt base alloys consist of complex mixed carbides in a CoCr-based solid solution-strengthened alloyed matrix. They are resistant to corrosion, erosion, abrasion and sliding wear and retain these properties at high temperatures, where they also resist oxidation. They have outstanding anti-galling properties. The wear resistance of Stellite alloys is due to the unique inherent wear characteristics properties imparted by a hard carbide phase dispersed in a cobalt alloy matrix. Stellite alloys are often used as a weld hardfacing on valves, spindles, and other wearing parts.

Background

The purpose of this document is to summarise the metallurgical issues relating to the weld hardfacing of various classes of steels, with a focus on the PTA and TIG processes.

Steel Families

Steels that are usually hardfaced can be divided into several main groups (There are also several classes of specialized steels, not listed here):

- **Carbon Steels (also called "Non-alloy" Steels)** – UNS Numbers start with G, AISI-SAE numbers are typically 10xx, 11xx, 12xx and 15xx.
- **Alloy Steels** – UNS Numbers start with G, AISI-SAE numbers are typically from 1300 through to 9700.
- **Tool Steels** – UNS Numbers start with T, AISI designations are of the style W1, H13, D2, etc.
- **Stainless Steels** – UNS numbers start with S, AISI-SAE numbers are 2xx, 3xx, 4xx, 2xx.
- **Duplex and Super-Duplex Stainless Steels**

Welding onto Carbon and Low-Alloy Steels - Preheating

The weldability of these steels is directly related to their hardenability, which results in the formation of a brittle heat affected zone (HAZ) below the weld if they are cooled too fast from the welding temperature.

Effectively, if the part is cooled too fast or if the preheat before welding is too low, then the steel in the HAZ is quenched from an austenitic structure to a brittle semi-martensitic structure directly after welding. The final structure is dependent on the cooling rate from the peak temperature. It is therefore standard practice to reduce the cooling rate by **preheating** the part before welding, especially for larger parts where the bulk of the steel can "quench" the overlay once welding is completed. A certain amount of preheat is usually necessary even for small parts with low hardenabililty, as it facilitates the hardfacing process itself.

The hardness and brittleness of the martensite and its tendency to form, and hence the weldability of the steel, are deduced from the CARBON EQUIVALENT as defined by the International Institute of Welding:

$$\text{C.E.} = \%C + \frac{\%Mn}{6} + \frac{\%Ni}{15} + \frac{\%Cu}{15} + \frac{\%Cr}{5} + \frac{\%Mo}{5} + \frac{\%V}{5}$$

Fig. 1 shows some typical preheat temperatures, the higher end of each temperature range should typically be used for larger parts and the lower end for smaller parts. The type of Stellite alloy being deposited should also be considered.

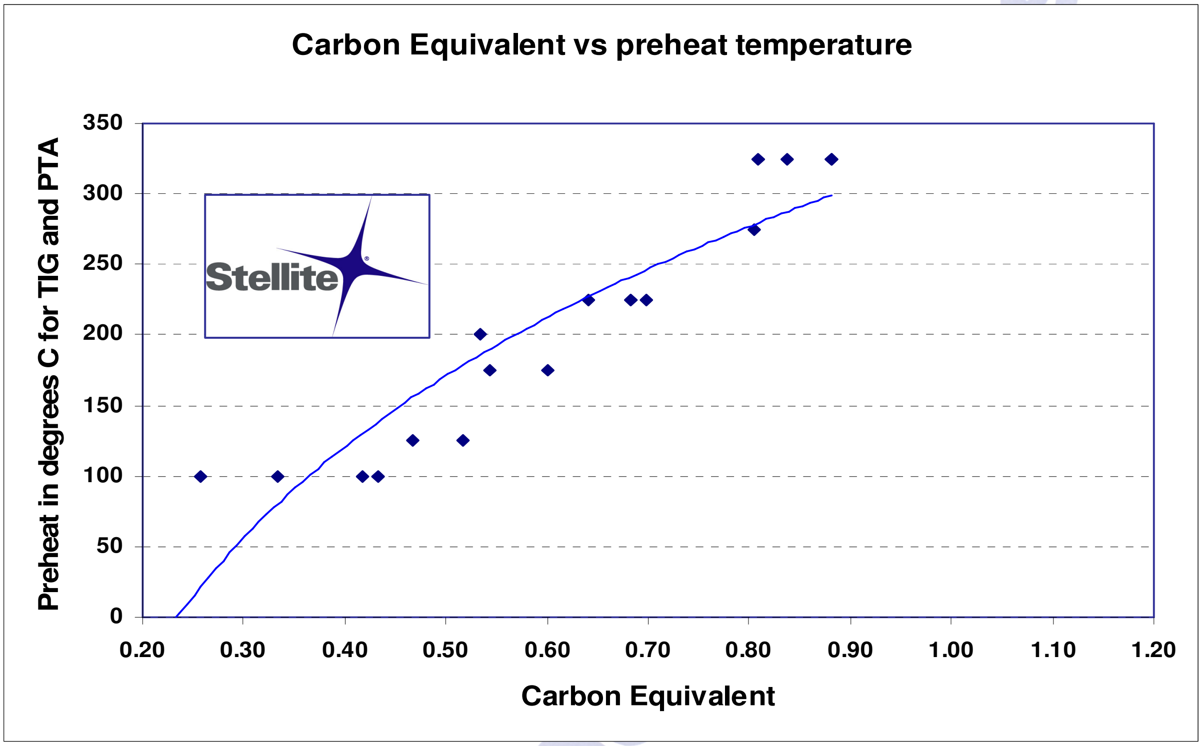

Figure 1: Typical Preheat Temperatures vs. Carbon Equivalent

Welding onto Carbon and Low-Alloy Steels - PWHT

For steels with a low C.E. (below about 0.50), it is usually possible to **avoid martensite formation** and HAZ cracking by preheating (typically to about 100-150°C) before welding, maintaining interpass temperatures during welding, and cooling slowly from the weld interpass temperature (for example by cooling in vermiculite).

A higher C.E. (about 0.50% and above) may mean that martensite formation is unavoidable. In this case the best approach is to obtain the original tempering temperature of the steel, as supplied before welding. This temperature can often be obtained from the steel certification and will usually be below 650°C (1200°F). Alternatively, a typical heat treatment temperature for the steel in question can be obtained from other sources. **The optimum post-weld heat treatment (PWHT) temperature is about 50°C (100°F) below the usual tempering temperature.** The aim is to temper the brittleness out of the HAZ sufficiently to prevent cracking, without over-tempering the rest of the part. Welded components are usually placed in a furnace directly after welding, without loss of heat, and held at the PWHT for 1-2 hours followed by a slow cool to prevent martensite from forming. It is not necessary to get the entire part thickness to reach this temperature, as it is only the surface layers which are at risk.

Medium-Alloy Steels, Martensitic Stainless Steels, Tool Steels and other specialist steels

The Carbon Equivalents (C.E.) of these steels is often above 1.10 and they present a hardfacing challenge. These steels are generally heat-treatable. They are best handled on an individual basis after assessing their carbon equivalent, hardenability, Ms and Mf temperatures and typical tempering temperatures, as well as the individual component and hardfacing requirements and customer specifications.

Austenitic Stainless Steels and Duplex Steels

From a hardfacing point of view, Stainless Steels are handled quite differently to carbon steels, tool steels and alloy steels. The carbon equivalent is not important, rather, the first thing to ascertain is whether the steel is austenitic, ferritic, martensitic, precipitation hardened, or a duplex steel. A summary of Stainless Steel "family relationships" is shown in **Figure 2** below. This Section deals only with Austenitic and Duplex steels.

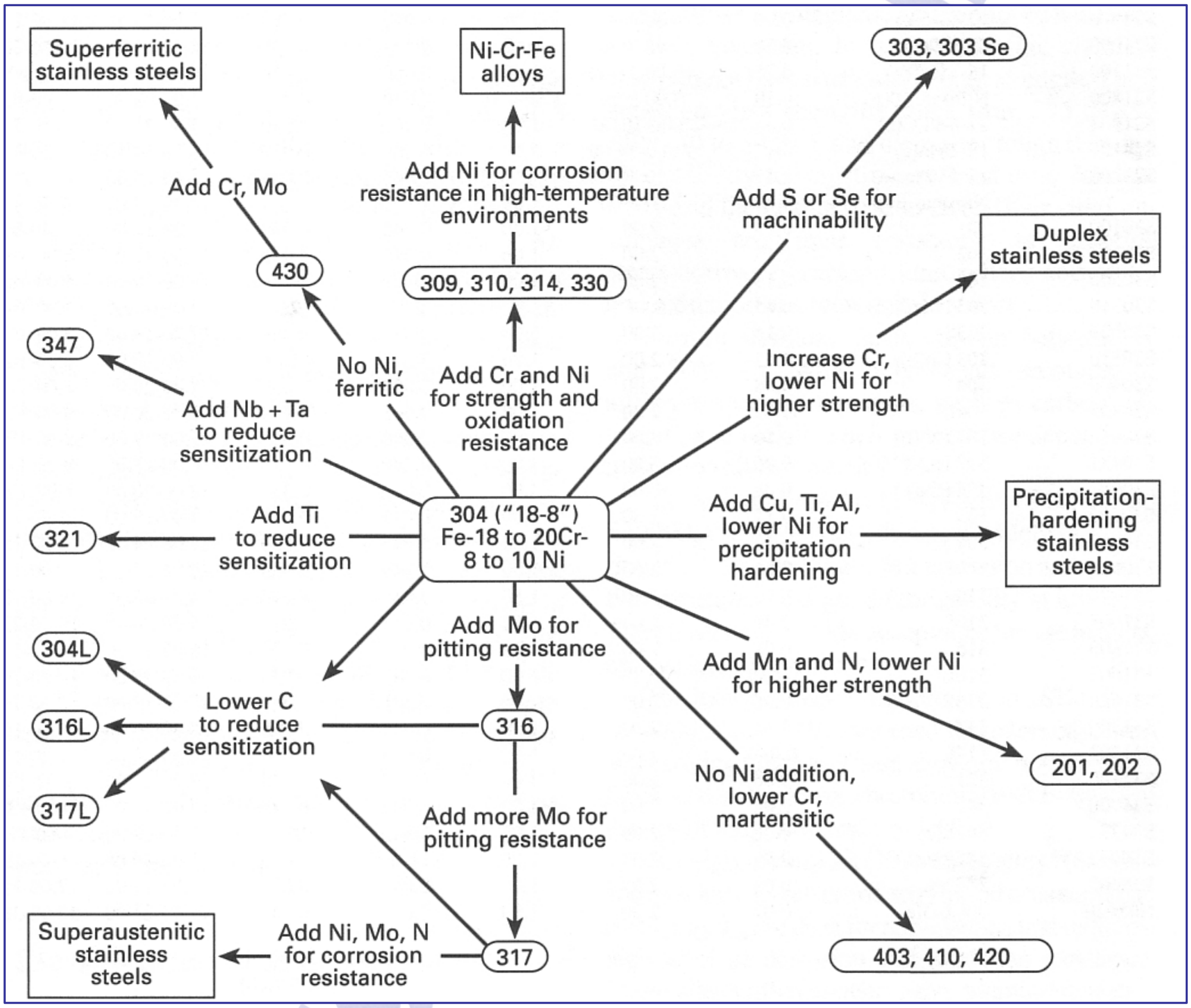

Figure 2: Family Relationships in Stainless Steels (from: A.J. Sedricks, Corrosion of Stainless Steels, 1979)

Austenitic Stainless Steels

Unlike many other steels, austenitic steels do not form brittle martensite in the heat-affected zone (HAZ), because the high-temperature face-centred cubic (f.c.c.) structure of the steel (austenite) is stabilised down to room temperature, mainly by the high nickel content and in some cases also by nitrogen, manganese and/or copper.

In principle, weld hardfacing onto these steels is not problematic from the point of view of the Stellite® deposit. They are usually welded using a low preheat temperature (50-150°C) followed by a slow cool in vermiculite.

The difficulty with austenitic steels is that during hard facing, carbon can diffuse from the Stellite alloy into the heat affected zone (HAZ). This carbon can form carbides on the steel grain boundaries, and in the process it depletes the Cr near the grain boundaries. The result is that the grain boundaries in the HAZ are less corrosion resistant than the steel overall, which can be a problem if the component is to be used in a corrosive environment (e.g. sea water). This process is known as "**weld decay**" or "**sensitization**" and is illustrated schematically in **Figure 3**.

It is necessary to be aware of this and to evaluate each individual application as to the risks involved. Usually additions of strong carbide-forming elements such as Nb or Ti help prevent sensitization, because the carbon then bonds preferentially with these elements rather than with the Cr. Such steels are called "**stabilized**" and the most common examples are AISI 321 and AISI 347 Stainless Steels. The alternative approach, namely lowering the steel's carbon content to reduce the risk of sensitization (e.g. the 316L, 304L, etc. steels) does not apply when hardfacing with Stellite alloys, as the overlay material provides the necessary carbon for sensitization to occur.

Another approach is to apply a nickel based "buffer layer" as a first weld layer with little or no preheat and a very low interpass temperature. The nickel inhibits carbon diffusion and the steel surface reaches lower temperatures during subsequent welding.

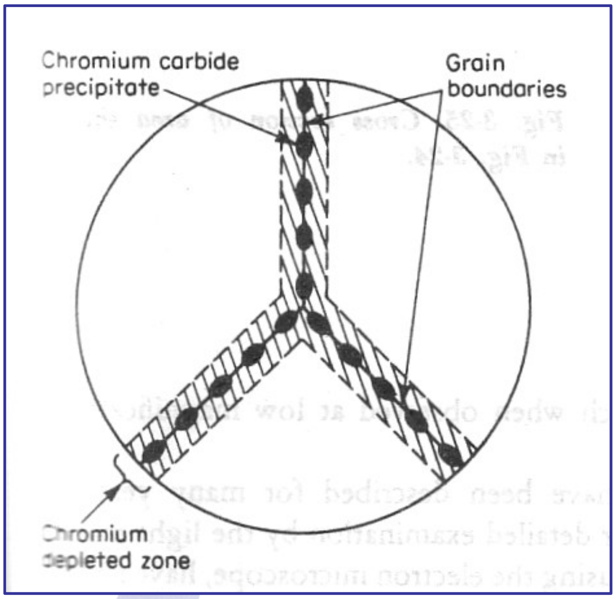

Figure 3: **Schematic illustration of sensitization (weld decay), which can occur as a result of carbon diffusing from the Stellite® alloy into the base steel and forming carbides on the grain boundaries. The resultant Cr-depleted zones have inferior corrosion resistance.**

Duplex and Super-Duplex Stainless Steels

Duplex steels consist of a mixed structure of austenite and retained ferrite (roughly equal proportions, with ferrite being the matrix). The duplex stainless steels alloying additions are either austenite or ferrite formers, extending the temperature range over which the phase is stable. Among the major alloying elements in duplex stainless steels chromium and molybdenum are ferrite formers, whereas nickel, carbon, nitrogen, and copper are austenite formers.

They are widely used in the oil and gas industry, typically where higher strength than that of standard austenitic steels is required. They also have better resistance to stress corrosion cracking (SCC) in chloride environments.

Typical Duplex Steels are as follows:

Fe 23Cr 4Ni 0.1N	(AISI 2304, UNS S32304)
Fe 22Cr 5.5Ni 3Mo 0.15N	(AISI 2205, UNS S32205)
Fe 25Cr 5Ni 2.5Mo 0.17N Cu	(AISI 2505)
Fe 25Cr 7Ni 3.5Mo 0.25N W Cu	(“Super Duplex” UNS S32760)

When hardfaced with Stellite alloys, these steels suffer not only from **sensitization** as described above for austenitic steels, but they are also susceptible to **embrittlement** due to the formation of secondary phases i.e. intermetallics, carbides and nitrides from extended exposure to elevated temperatures. Significant secondary phase precipitation may lead to a loss of corrosion resistance and sometimes to a loss of toughness.

From a weld hardfacing point of view, their biggest drawback is the fact that when subjected to the typical thermal cycle of a welding process, they very easily and in a short time form a variety of brittle phases such as sigma (σ), chi (X) and alpha-prime (α’) phases. This occurs when they are subjected to temperatures of 300-1000°C (570-1800°F).

This is virtually unavoidable because during weld hardfacing the surface undergoes melting, and so even if the bulk of the material remains below 300°C, there is always a zone in-between which will experience temperatures in the embrittlement range, even if only for a brief period of time. This is why the minimum of pre-heat is recommended for duplex stainless steels. Depending on the component geometry and the type of Stellite alloy being deposited, the fastest possible cooling rate from the welding interpass temperature needs to be applied in order to minimise the time spent in the embrittlement zone. Normally, the interpass temperature is maintained around 150 to 200°C, in order to avoid precipitation temperatures. Another approach is to apply a ductile “buffer layer” such as Nistelle® 625 as a first weld layer with little or no preheat and a very low interpass temperature. During subsequent application of the Stellite overlay the steel surface is shielded from the weld pool and reaches lower temperatures than it would otherwise have reached.

It is necessary for design engineers to be aware of these issues and to evaluate the potential effects in the intended application, for example by considering the individual steel, the component geometry, and the speed at which brittle phases would be expected to form in each particular steel.

Dilution

Stellite alloys are cobalt based. When they are applied to steels by hardfacing, there is inter-mixing of the Stellite alloy and the steel, resulting in a higher iron content in the overlay, especially in the first layer. In Stellite alloys this generally has the following effects:

- It decreases the corrosion resistance of the Stellite alloy in extreme corrosion environments, because the Cr content drops to 20-25%Cr (but this is still better than many stainless steels).
- It decreases the hardness (see next Section).
- It decreases the wear resistance, by virtue of
    - increase in the stacking fault energy of the Co-matrix, which affects mainly the galling properties
    - decrease in the overall carbon content, which affects the general wear resistance and hardness.
- Dilution by Fe or Ni may be expected to reduce the brittleness by virtue of the fact that the content of brittle carbide phases is decreased.

What constitutes an acceptable level of dilution will depend upon the service requirements, and in particular what level of corrosion and wear resistance is required. However it is standard practice to design components for hardfacing in such a way that the final working surface of the hardfacing will be in the second or third weld layer, after final machining. Typically this implies a final overlay thickness of at least 1.6mm (0.065") and preferably 2.0mm (0.080").

Work done by Deloro Stellite in the 1990's on the topic of weld dilution of Stellite hardfacing alloys, was presented at the *1998 AWS International Welding and Fabrication Exposition* as well as several other conferences. The primary aim of this work was to demonstrate the lower dilutions obtainable by PTA deposits as compared to the more traditional welding methods. **Figures 4 to 6** below are taken from this work.

Figure 4 shows that the dilution levels in Stellite® 12 welds drop off rapidly from about 50%Fe at the weld fusion line, to about 5%Fe at a distance of 4 mm (0.16") from the fusion line. For PTA deposits, the dilution drops off more rapidly than for TIG deposits, reaching 10%Fe at less than 1mm (0.04") deposit thickness, whilst for TIG deposits dilution levels below 10%Fe are typically only reached at deposit thicknesses of over 2mm (0.08").

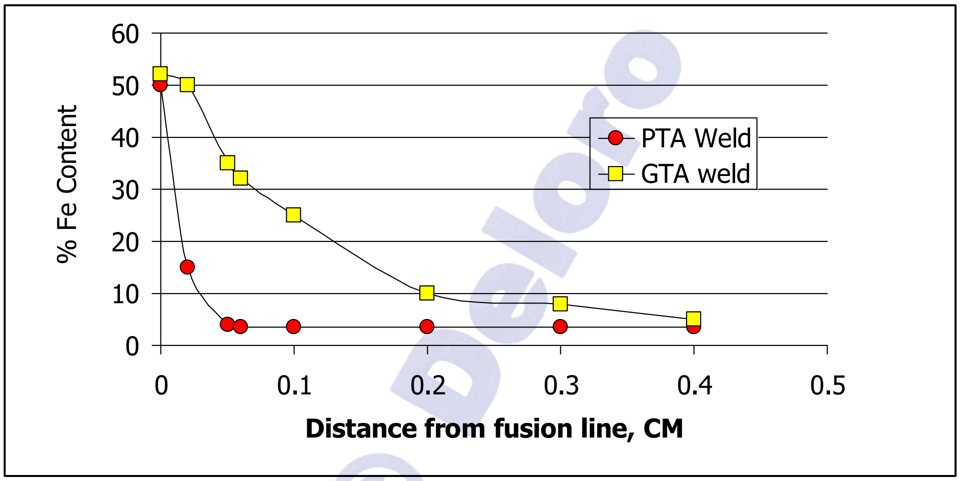

Figure 4: Typical Dilution levels in Stellite® 12 GTAW (TIG) and PTA overlays.

Figure 5 shows that the hardness drops more or less linearly with dilution up to levels of about 15%Fe, although the curve seems to start flattening out at the highest iron percentages. This "flattening out" tendency at higher iron contents is much more pronounced for Stellite® 6 overlays, as can be seen from **Figure 6**.

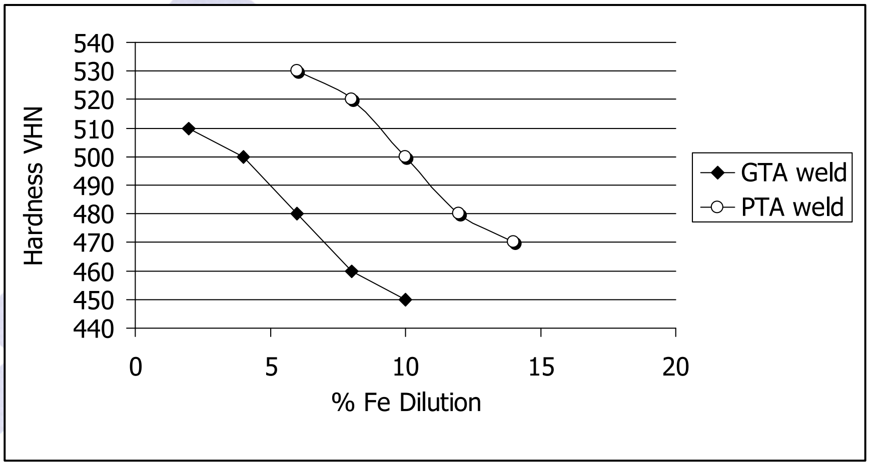

Figure 5: Effect of dilution on the hardness of Stellite® 12 GTAW (TIG) and PTA overlays.

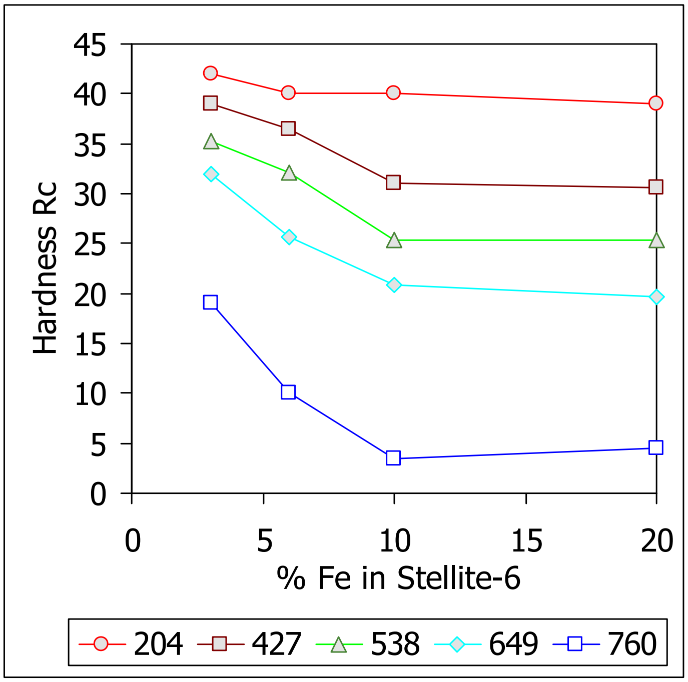

Figure 6: **The hot hardness of Stellite® 6 weld overlays drops off sharply as iron content increases up to 10%Fe, but at higher Fe contents the drop is insignificant (up to 20%Fe). The legend shows temperatures in °C and represents tests done at 400, 800, 1000, 1200 and 1400°F respectively.**

CONTACT: **Please refer to our web site http://www.stellite.com for contact information.**

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