Stainless steel automotive and transport developments

by Paul Snelgrove

Stainless steel is widely used in car exhaust systems and for auto parts such as hose clamps and seatbelt springs. It will soon be common in chassis, suspension, body, fuel tank and catalytic converter applications.

Stainless is now a candidate for structural applications. Offering weight savings, enhanced "crashworthiness" and corrosion resistance, it can also be recycled. The material blends tough mechanical and fire-resistant properties with excellent manufacturability. Under impact, high-strength stainless offers excellent energy absorption in relation to strain rate. It is ideal for the revolutionary "space frame" car body-structure concept.

Amongst transport applications, Sweden's X2000 high-speed train is clad in austenitic. The shiny surface needs no galvanising or painting and can be cleaned by washing. This brings cost and environmental benefits. The strength of the material allows reduced gauges, lower vehicle weight and lower fuel costs. More recently, France chose austenitic for its new-generation TER regional trains. Bus bodies, too, are increasingly made of stainless. A new stainless grade that welcomes a painted surface is used for tram fleets in certain European cities. Safe, light, durable, crash resistant, economical and environment friendly, stainless seems the near-ideal solution.

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The average passenger car uses about 15 to 22 kilos of stainless steel. Mainly found in the exhaust system, stainless also occurs in sundry small parts. Stainless steel has been used in long distance and commuter trains since the 1930s. Today, U.S. high-speed trains or Sweden's X2000 are impressive example of stainless in rail transport application. Bus bodies, too, are increasingly made of stainless steel and some tram fleets are now clad in stainless. Major, new automotive applications are in the pipeline, and transport uses are set to gain ground.

These days, automobile constructors have to build lightweight vehicles. In the past, the only alternative to conventional materials has been so-called light metals. These, however, are expensive, and lend themselves ill to welding. Stainless steels have outstanding mechanical properties. Combining exceptional weldability and formability, they enable designers to make stainless steel parts as light as their "light metal" counterparts. The number of parts can often be reduced and assembly complexity optimised. Stainless steel can thus have economic benefits over competing materials.

Stainless versus light metals

One grade of particular interest is AISI 301L (EN 1.4318). This stainless steel has particularly remarkable work-hardening properties, and high tensile strength, which confer outstanding "crashworthiness" (resistant behaviour of the material in an accident). It also means it can be used in thin gauges. Other advantages include exceptional formability and corrosion resistance. Today, this is the preferred grade for structural application in railway carriages. Experience gained in this context can be readily transferred to the automotive sector.

Exhaust systems

Most cars have stainless in the exhaust, around the catalytic converter area. This is the main, well-established automotive growth market for stainless steels. Exhausts release polluting hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOx) into the atmosphere. The catalytic converter became a must in densely populated urban regions of the U.S. and Japan in the 1970s and has since become obligatory in many parts of the world. It changes HC, CO, and nitrogen oxides into harmless water, carbon dioxide, and nitrogen. However, its action changes the temperature and the corrosive conditions in the system. Non-corrosive materials are thus needed to prevent rusting.

An exhaust system has a hot end (the exhaust manifold, down pipe and catalytic converter) and a cold end (the resonator, intermediate pipe, silencer and tail pipe). At the hot end, the material must resist creep (due to high temperatures) and oxidation. Special "refractory" stainless grades have been developed for this area. The cold end has to deal with agents, such as salt, used on the roads to combat snow and ice. Both inside and outside corrosive factors are thus at work. The hot end really requires high-temperature austenitic stainless - the more highly alloyed grades such as 309 or 310 (25% chromium, 20% nickel). Towards the cold end, type 304 (18% chromium, 9% nickel) or ferritic type 409 (12% chromium, 0% nickel) will do. Austenitic grades, which have added nickel, are more easily formable. They are also more resistant to corrosion, the presence of which could be cosmetically undesirable.

Many manufacturers use ferritic for the entire system. High-end names use austenitic throughout, largely for its visual allure.

All-stainless catalytic converters

Exhaust systems are an example of stainless winning market share from other materials. Next will come the all-stainless catalytic converter. Currently, the catalytic surface is ceramic material, which makes it large and heavy. Now, size and weight can be reduced by replacing the ceramic substrate with stainless steel foil, of 40 microns or less. Stainless also has the advantage of conductivity, so the catalytic converter can be preheated electrically. The catalytic effect is thus there from the moment the engine is started. At present, driving down to the local store might generate no catalytic effect. With stainless steel, the 'cat' reaches working temperature in seconds.

Trim, gaskets and suspension systems

Ferritic for interior and exterior decorative trim is a well-established growth area. It is easy to work, and specific grades containing molybdenum and niobium have high corrosion resistance and excellent appearance when moulded.

Stainless is increasingly used in parts such as hose clamps, head gaskets, pump bodies, heat shields, windscreen wipers, airbag inflation-gas containers and seatbelt springs. This is due to its corrosion resistance, manufacturability (fabrication-friendliness) and tough mechanical properties.

In the past, cylinder head gaskets were made of a "sandwich" of asbestos and steel sheets. Today, with the total ban on asbestos and the higher pressures and temperatures of modern engines, a new design is needed. One of these gives excellent resistance to heat and corrosion. It uses 3-5 layers of thinly rubber coated, hardened stainless steel sheets, each 0.25mm thick or less.

Using various demonstration models, it has been shown that stainless can be used to advantage in suspension systems. This promising application awaits further development.

Fuel tanks

Producers also have high hopes for fuel tanks as a major new market. With tighter environmental legislation, becoming effective in California in 2004, current tank materials will have difficulty meeting emission laws. Some automotive manufacturers are considering stainless tanks for their entire U.S. vehicle range.

A stainless steel tank neither leaks nor absorbs vapour. It does not require a protective coating and it can be fully recycled. New hydro-forming techniques make it easy to form it into complex shapes for tight chassis spaces.

Emerging structural advantages

Stainless steel is an excellent candidate for structural applications in cars. The competition between different materials in this area is intense. Choice centres on mass saving, formability, weldability, corrosion resistance, fatigue resistance, cost and environmental factors. Safety and crashworthiness, especially, should take priority. Crashworthiness refers to the ability of a vehicle's structure to protect the passengers. It now also means the ability to withstand minor accidents with little damage. Car designers today seek the very best stiffness, mass-reduction and safety performance.

Strain rate sensitivity

The dynamic energy involved in a crash is first absorbed through the plastic strain of the material. The higher the material's mechanical properties, the more energy it can absorb. The mechanical properties of stainless grow with an increase in the dynamic strain rate. The faster the loading is applied, the more stainless resists deformation. This makes for good crashworthiness since, in a crash, loading is applied very rapidly.

A well-designed stainless structural part will also collapse progressively, in a controlled and predetermined way. This has obvious passenger-safety advantages. Of all steels, high strength stainless offers the highest energy absorption capability in relation to strain rate.

Self-passivation

Stainless shows excellent corrosion resistance in a many atmospheres, due to a phenomenon known as passivity. The material protects itself from its environment by forming a very thin passive film, or layer, at its surface. Strongly bonded to the substrate, this film prevents further contact between the metal and surroundings. This passive layer is also self-healing. If there is chemical or mechanical damage to the film, repassivation will occur, in oxidising environments.

Light and clean

Stainless steel is a light material, with a specific stiffness equal to that of so-called light alloys. High strength grades provide a unique combination of strength, fatigue resistance, ease of forming and ease of joining (by welding, brazing, adhesive bonding, etc). High strength stainless means reduced thickness and, thus, reduced weight. The absence of surface protection both reduces weight and eliminates chemical emissions from anti-corrosive protection processes.

The space frame

The exciting, new "space frame" concept, still experimental, may revolutionise vehicle structure. It involves bonding non-structural bodywork, like a skin, to a tubular framework of thin-wall tube. The framework is the structure. This concept would enable very rapid design of a new car. Space frames, currently used in some niche vehicles, could have great potential for stainless steel.

Rail transport

Those merits that commend stainless steel to the automobile sector have long seduced train designers. The first example of stainless steel passenger rolling stock was introduced as early as 1932. Canadian Pacific acquired such rolling stock in the 1950s, for a transcontinental fleet. This classic fleet is still going strong and looking great today. In 1993, the current operator chose to renovate the elegant, period rolling stock, rather than invest maybe twice as much on new trains. The glinting new interior also features lavish use of stainless steel.

A similar design was later used extensively in Europe, Asia, Australia and South Africa. Japan introduced stainless passenger stock in the late 1950s and early 1960s. Later, in Europe, Sweden came out with its all-stainless X2000 high-speed train. An impressive, recent U.S. example is the new-generation, stainless steel, bi-level, intercity "Superliner," supplied to Amtrak in the early 1990s.

The huge railroad cars of the Shuttle, that carries lorries and cars under the English Channel, are also made of austenitic. This specific grade has 7% nickel, 18% chromium, low carbon content, and 0.15% nitrogen. The tiny amount of nitrogen has a major effect in reinforcing mechanical properties. This material is very light and strong. It is also highly resistant to corrosion from the tunnel's aggressively humid marine atmosphere.

Stainless steel has long been a standard option for commuter trains, especially since the 1950s. Many of these trains are still around, and in good shape after more than 40 years of service life. Railway operators specified stainless steel at that time mainly because of low maintenance and repair requirements. Today, the material is increasingly being considered in terms of safety. Recent dramatic accidents have made crashworthiness a big railway issue. They have highlighted the need for the best mechanical and fire-resistant properties in materials used.

Underground trains too are ideal candidates for stainless, for considerations of life cycle costing and, particularly, crash-behaviour and fire-resistance properties. The New York subway, for example, moved over to stainless for these reasons. In extreme heat, stainless does not readily melt, so passengers would be well protected in the case of a tunnel fire.

Bus bodies

Stainless steel is already widely accepted for use in structural frameworks and body panelling of buses and coaches. Steels used range from low-grade (but highly effective) stainless to austenitic grades such as AISI 301, 304 and 430.

This market, especially well established in Italy and, for example, South Africa, is rapidly extending. In Europe, manufacturers in Spain, for example, are heading towards full use of stainless in buses. Volvo and other European manufacturers offer several stainless models. Some U.S. manufacturers, too, have moved over entirely to stainless. Indian manufacturers are also currently working towards using it, particularly in chassis structures.

Life cycle cost is significantly reduced by the material's easy-maintenance properties and corrosion-resistance. This latter factor is important for operators located in humid environments or areas where roads are salted. In crash situations, absence of body corrosion means absence of weak points. This and the material's tough mechanical properties ensure optimal passenger protection. Other relevant advantages include easy manufacturability, increased passenger-capacity, weight-savings and the self-passivation behaviour of stainless when damaged.

Stainless steel you can paint

Recently producers have developed a new 12% chromium grade that lends itself to surface decoration. Its use in tram fleets and light urban railways has become a significant market growth area. While fleet owners can happily apply their company livery, the paint used serves no protective purpose.

There seems to be plenty in the stainless automotive and transport sector to keep R & D departments buzzing. A recent technology for joining open sections of different materials without welding, for example, will allow entirely new stainless steel automotive applications. This is currently "under wraps." Many other applications of technical advances wait in the wings, and stainless steel's automotive and transport future is looking bright.

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