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Manufacturer - Supplier to OEM's, Plants and Process Industry
Heat, Wear, Abrasion, Pressure and Corrosion Resistant Alloys for Specific End Applications
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Fabricated and Welded-Parts, Components & Assemblies in Steels and Stainless Steels
Engineering & Metallurgical Consulting

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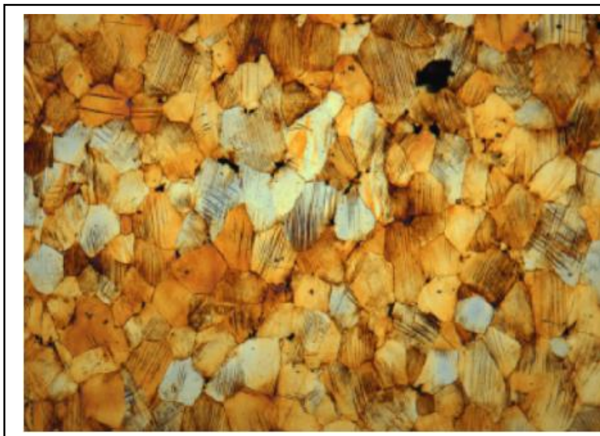
Austenitic Manganese Steel (AMS) / Hadfield Steel -Uses, Limitations & Impediments

The original austenitic manganese steel (AMS), containing 1.2% C and 12% Mn, was invented long back in 1882 by Sir Robert Hadfield still holds prominence to-date without much change in its invented composition. Hadfield's steel was unique that it combined high toughness and ductility with work hardening and with good resistance to combat wear at service temperatures up to 250°C. The slide # 1 below shows microstructure of a work hardened AMS at x100.



AMS Applications

Equipment for handling & Processing Earthen Materials	Rock crushers, grinding mills, dredge buckets Power shovels, bucket teeth, tooth adaptors, pans Pumps handling gravel and rocks Clay crusher rolls Liners
Automobile industry	Fragmentation hammers, shredders, grates
Military	Tank track pads
Railway track work	Frogs, switches, and crossings
Metal-to-metal wear	Sprockets, pinions, gears, wheels, sheave wheels Conveyor chains, drag-line chain, wear plates, shoes In Steel mill weld overlays on couplings, spindles, pinions and other items working under heavy impact loads

Hard to cut AMS finds its end use in safes, and prison cell bars. AMS also develops a favourable wear pair with alloy steels so that it can be used a bushing material in demanding mining applications. *(Do see application note on AMS bushes for mining application, developed and manufactured by ACMECAST*)

Recently, new light weight alloys with very high manganese and aluminium contents for armour plates applications are being developed. Due to its austenitic nature, it has no magnetic response and therefore, makes good wear plates for the bottom of electro-magnets. AMS use is understood to be growing in LNG applications, cryogenic LNG transportation equipment and vessels.

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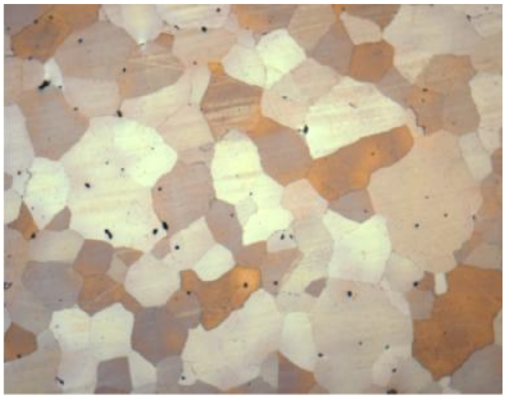
Impediments

Cleaning

Removal of gates, risers, feeders and vents can be accomplished in a few different ways for austenitic manganese steels (AMS). If castings are allowed to cool to ambient temperature after shakeout, most of the rigging can be broken, flogged off from the casting. The casting will be fairly brittle at this stage and removal of gates with an impact force can be quite effective. However, once heat-treated it will no longer be possible to break anything size of the casting. Slide # 2 below shows microstructure of aptly quenched AMS magnified at x100.



Cutting will be required to remove gating's' in heat-treated in condition which can be accomplished by abrasive cutting, torch cutting, or arc air cutting. Torch cutting is somewhat difficult and tedious as it produces high volume of smoke owing to high manganese content in AMS. Adequate designed dust and smoke collectors are required to accomplish the job. Care must be taken not to overheat the AMS when doing hot work. Fast cuts and moving around the casting to avoid concentrating the heat are advisable in order to mitigate effect of overheating. With the advent of new technology plasma cutting is possible for cross-section 10-75 mm successfully.

Machining-ability

Austenitic manganese steel (AMS) wear resistant properties also makes it very difficult to machine, at best. That impedes or restricts its use. Though it is known "difficult" to machine (usually has a yield strength of only 345-415 MPa), hard to maintain close dimensional tolerances, or perform intricate milling operations; resorting to fettling, cutting and limited grinding after casting was the norm in earlier days. Today with several advance high-end cutting tools, various insert geometries and tool holders that have been successfully developed by manufacturers across the globe to overcome such limitations when used in conjunction with robust and rigid machines; makes AMS possible to turn, bore and mill successfully if not with ease. Nevertheless, AMS is not well suited for components that demand close-tolerance machining or that must resist plastic deformation when highly stressed in service. Newer techniques of hammering, pressing, cold rolling, or explosion impacting of the surfaces do enable raising the yield strength to provide a hard surface on a tough core structure.

From our experience, we believe AMS does not machine, like other steels or alloys. It typically requires negative rake angle for acceptable machining (though many advocate using positive rake angle aided with cutting fluid). Further, relatively low surface speeds with large depths of cuts produce the best results. Apparently, such cutting parameters produces high cutting forces. It is paramount that the equipment and tooling must be robust enough to withstand these cutting forces. Any chatter, or vibration of tooling can add to the work hardening of the surface being subjected to machining. Most cutting is achieved in dry condition without any lubrication. During machining of AMS it is better to continuously remove the work-hardened zone with successive cut(s). Small finishing cuts or tool chatter will lead to hardness build up making the surface nearly unmachinable as the tool will only rub the surface without any successful metal removal. Drilling and milling of AMS is feasible, though we would prefer to cast the hollow profile into the part itself. An intelligent technique would be place mild steel inserts or cores in the part where holes are required, which can be further machined, drilled or tapped, as the case be.

Corrosion Resistance

Manganese steel is not corrosion resistant. But where corrosion resistance and abrasion are combined (as they frequently are) in mining and manufacturing environment, AMS may deteriorate or be dissolved at a rate only slightly lower than that of carbon steel. If

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the toughness or non-magnetic behaviour of AMS is essential for marine application, coating protection by galvanizing is useful in obtaining satisfactory results.

AMS is not satisfactory resistant to wear by stream of air-borne particles (impingement erosion) such as in sand blasting or grit blasting equipment and hence, it is suggested not to be used in such service. Though in our experience, we have observed many such equipment users still using AMS in applications-as bells, impeller, and cover plates.

Welding

Welding is an issue with some grades of AMS, as at higher temperatures it may lack the strength and ductility to withstand severe welding stresses. Welding of AMS requires controlled conditions and use of correct, compatible weld fillers or coated electrodes. Many end users often hard-face AMS parts to increase the service life, enhance combat wear-abrasion, or maintain service life of parts that demand frequent replacement. It is not resistant to high temperature oxidation and its creep rupture properties are far lower than those of Fe-Cr-Ni, Fe-Ni-Cr austenitic stainless steels. When properly done, electric arc welding is the preferred method of joining and surfacing AMS. Electrodes for arc welding AMS are commercially available in many compositions that are used for surfacing, weld repair, and for joining AMS to itself or carbon steels. But factors that are frequently overlooked are the losses in carbon, manganese and silicon that occur during welding. Just like any other hot work on AMS the welding inter-pass temperature must be kept below 260°C to avoid embrittlement. In addition, %P content in the weld filler must be kept below 0.03% to minimize or avoid hot cracking. Re-heating above 260°C must be avoided. Temperatures at and above this level will cause precipitation of acicular carbides, that can considerably reduce the fracture toughness of AMS. This effect is time and temperature dependent. Exposure to longer time and higher temperatures both result in losses of toughness.

Effects of Temperature

Excellent properties of 12-13% AMS between -45°C to 205°C make is useful for all ambient temperature applications, including cryogenic or sub-zero temperature working conditions. AMS is not recommend for high-temperature wear applications owing to its micro-structure instability attributed to primary and secondary creep failure mechanisms upon continuous exposure to temperature range 260°C-870°C.

The effects of temperature on mechanical properties (both in tension and compression) of AMS reveal that there is an increase in yield strength with decreasing temperature with a corresponding drop in ductility and ultimate tensile strength. The variation in strength and ductility is non-uniform, but AMS maintains its room temperature ductility up to -100°C, which is attributed to prominent deformation twinning at lower temperatures (below 0°C) and at higher temperatures (above 0°C), strain hardening is due to twinning, strain aging, and stack fault formation. Some hardening due to Cottrell (famous physical metallurgy exponent, Sir Alan Cottrell) clusters and carbide precipitation have been observed at temperatures above 300°C.

At -75°C, cast AMS retain 50-85% of their room temperature impact resistance. They are considerably brittle at liquid-air temperature -185°C, but at all atmospheric temperatures encountered by end applications in railways tracks, mineral, and mining, they exhibit outstanding toughness that imparts reasonable factor of safety when compared to ferritic steels at sub-zero(cryogenic) temperatures.

Thermal expansion characteristics of AMS are similar to those of other austenitic materials. The expected change in length upon heating is about 1.5 times that of ferritic steels. Phase transformation to pearlite and precipitation of carbides significantly influences the expansion coefficient in the range from 370°C to 760°C.

Magnetism

The un-transformed austenite of 12-13% AMS is virtually non-magnetic, with an approximate permeability of 1.03 or less. This permits the use of AMS where a strong, tough, non-magnetic material is required in magnetic cover plates, collector shoes of travelling cranes, stator-core parts for generators and motors, liner plates for storage bins holding materials that are handled by lifting magnets, magnetic-separator parts, instrument testing devices and furnace parts located in the magnetic fields of

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induction furnaces. Cast and wrought AMS is probably the most economical material for non-magnetic parts should machining is not required.

The author, on his visits to several coal fired power plants in India observed coal pulveriser equipment, like crushers and ring granulators using mild steel or carbon steel beater and hammer heads instead of AMS. On inquiring, surprized to learn that the power plants refrained from using AMS owing to its non-magnetic behaviour in spite of superior impact crushing capability. Reason being, used or chipped/ broken beater and hammer heads often get mixed with pulverized coal meal that go undetected in the fuel feed conveyor, eventually reaching the combustion circuit damaging the conveyor systems, and expensive turbomachinery parts. Contrarily, all the worn-out iron/steel beater head and hammers end up in coal meal intended for pressurized hot air injection, fails to burn/oxidize in the fire-ball / combustion chamber (injected through tangentially placed coal nozzle tips), leading to molten metal slag trap at the bottom of the power turbine equipment.

We suggest instead a solution to end users and power plants to overcome such an impediment. Lack of magnetism is indeed a disadvantage when AMS is used in components of material handling systems that depend on magnetic separators to remove tramp iron from the process stream before it enters the crushers, grinders, machinery and turbo-machine parts. When there is the possibility that AMS parts may become detached from working system and fall into the processing stream, it is advisable to cast mild steel inserts in the austenitic manganese steel cast parts. The inserts must be large enough to provide enough ferromagnetism necessary for magnetic separators to detect and remove the lost parts, broken elements, etc., so that they do not enter working machinery resulting in damage and impromptu plant shut down.

Production

AMS can be produced in any of the conventional steel making process. Current, practice includes electric arc furnace (EAF) and electric induction furnace (IF). Some manufacturers choose acidic furnace lining as a lower cost option, but acidic lining is attacked by manganese oxides, results in silicon pick up in melts during successive heats. ACME uses basic lined furnaces and prefers neutral lining for modified AMS products range. Advantages of EAF melt route is using silicon burn to stir the metal, achieve close control of elements in alloy chemistry, removal of oxides, and lowering of gas levels (de-oxidized melts, enhances fluidity, bi-film formation).

It is highly beneficial to keep levels of non-metallic inclusions like hydrogen, oxygen and nitrogen below 150, 300 and 300 ppm (parts per million). Lower the S & P levels better is the product. In particular, nitrogen levels above 300 ppm is known to result in severe gas porosity and pin hole gas defects in AMS castings. Buyers and end users are sacrosanct about chemical test certificate compliance to alloy chemistry or Standard specifications, but are often oblivious to H, N, and O ppm levels in melt and actual solidified AMS casting which significantly affects properties and its useful life; that a competent metallurgist does not miss out.

The fluidity of AMS is quite good to enable pouring it into complex shapes and geometries at low superheats with ability to place complex cores to achieve desired hollow shapes.

Research reveals that mechanical properties of AMS are greatly enhanced by finer grain size. Strength and ductility can be as much as 30% greater for fine-grained AMS. Slides # 3 and # 4) represent solidification cross-section of a 50 mm x 50 mm broken bars to reveal
as-cast grain size.

Slide # 3

(12% Mn AMS Poured at Low Pouring Temperature)

Slide # 4

(12% Mn AMS Poured at High Pouring Temperature)

AcmeCast has worked continuously over the years to develop modified AMS alloys to suit industry specific end application needs; including grain refined AMS using titanium (expensive low aluminium eutectic ferro-titanium and not titanium scrap!), niobium, rare-earth-metals (REM) and calcium-silicon grain refiners along with directional solidification techniques ensuring pouring of melts with low superheats, optimal risering placed at casting geometries unaided or aided with exothermic/insulation pre-shaped sleeves; knowing well that AMS is a wide freezing range alloy susceptible to dispersed micro-shrinkage, micro-porosity, grain segregation and precipitation of carbides at grain boundaries; all badly affecting fracture toughness values of cast product.

Selection of Cast Cross-section of AMS

One final consideration when selecting AMS or AMS Grade is the section thickness of the desired part. As section thickness increase it becomes harder to obtain good casting properties in AMS or to curb casting defects and flaws. AMS possess low thermal conductivity when compared to other steels and to obtain good toughness it requires to rapid quench post solution annealing. Also, higher the cross-section of casting more is the probability of precipitation of carbides that could not successfully phase transform in any heat treatment cycle. Therefore, it is desirable to keep the cross-section less than 150 mm or alternatively adopt rapid solidification (chills) and directionally solidification techniques to obtain good casting properties.

On an optimistic note, ever since its discovery austenitic manganese steel is still used for harsh applications that require high level of toughness. Though its total global production is rather small compared to other carbon, and alloy steels, austenitic manganese steel yet turns out to be *best* alloy option in many applications where other alloys fail.

For custom-made end application solutions in Austenitic Manganese (10-14%) Steels or High Austenitic Manganese (14-28%) Steels, or to develop parts, spares and consumable wear components contact AcmeCast

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