The Role of Cap Plies in Steel Belted Radial Tires

by
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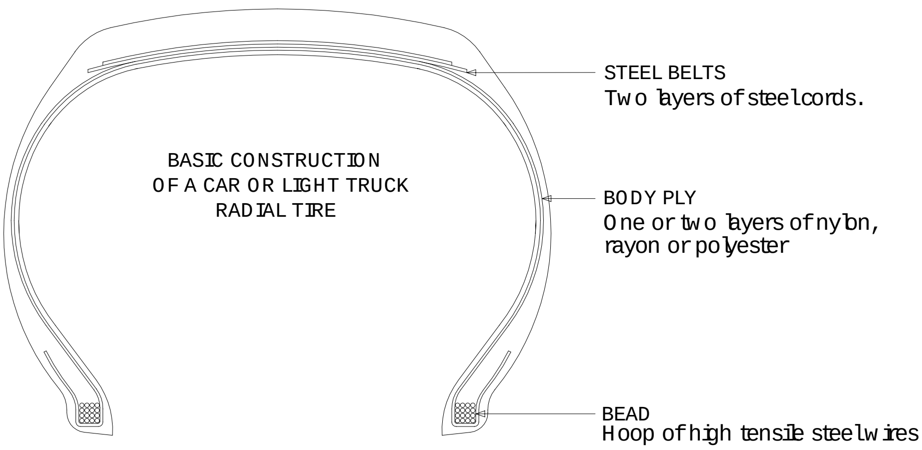
Introduction

Separation between the steel belts of radial ply car and light truck tires has been a problem that has been with tire manufacturers since the invention of the steel belted radial tire. The problem of separation between steel belts arises due to the conflicting nature of placing two layers of stiff steel cords within a flexible matrix of rubber and then deforming the composite arrangement.

Over the years, tire manufacturers have devised means of dealing with this problem and even now continue research and development to improve their products.

The problem and the solutions are explained and discussed.

Radial tire construction.



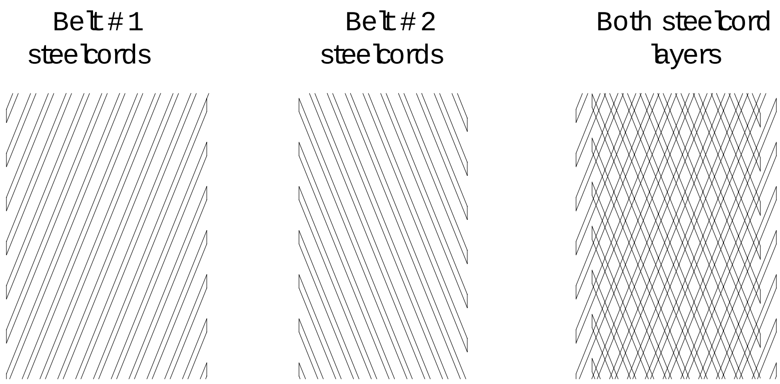
This diagram shows the steel and textile reinforcements, the skeleton, of a radial tire.

The beads are formed from a bundle of high tensile steel wires. The number of wires and their arrangement largely depend on the size of the tire and the strength required. The purpose of the bead is to anchor the tire to the rim.

The body ply, or plies, provide the main reinforcement of the tire. The ply is formed from parallel rubberized textile cords that are aligned at 90 degrees to the circumferential centerline of the tire. Hence the name – radial ply tire. The ply is looped under the beads, which act as an anchor. Because the plies are aligned radially they impart strength to the tire in the radial direction but no strength to the tire in the circumferential direction.

The steel belts are formed from two layers of rubberized parallel steel cords that are aligned at an angle usually between 15 and 30 degrees to the circumferential centerline of the tire. They mainly impart strength in the circumferential direction and therefore complement the body plies that impart strength in the radial direction.

The manner in which the steel belts are aligned with each other is shown in the diagram below:



The opposition of angles gives a certain degree of stiffness or rigidity in much the same way that the opposing grains give plywood its stiffness.

It is this stiffness that gives support to the tread, reduces squirming and shuffling of the tread during manoeuvers and thereby gives the long tread life that radial tires are renowned for.

However this stiffness creates problems.

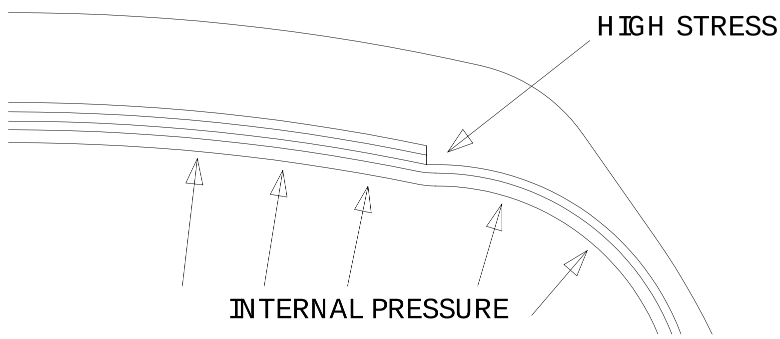
THE PROBLEMS

Stresses caused by tire inflation

Stresses occur in the rubber matrix surrounding the steel belt edges as soon as any steel belted radial is inflated.

The body ply and surrounding rubber matrix are flexible and extensible and the internal pressure forces them to stretch and grow outwards, but the steel belts are much stiffer and much less extensible and have much greater resistance to the stretching and growing.

Across the main body of the steel belts the greater stiffness and inflexibility of the steel belts restrain the body ply and rubber but this restraint suddenly ends at the belt edge and the body ply and rubber are free to stretch and grow outwards:



This sudden change causes high stress in the rubber matrix surrounding the belt edge.

This stress arises as soon as the tire is inflated and is always present whether a tire is used on the road or only mounted as a spare.

Stresses that arise from vehicle load and centrifugal load.

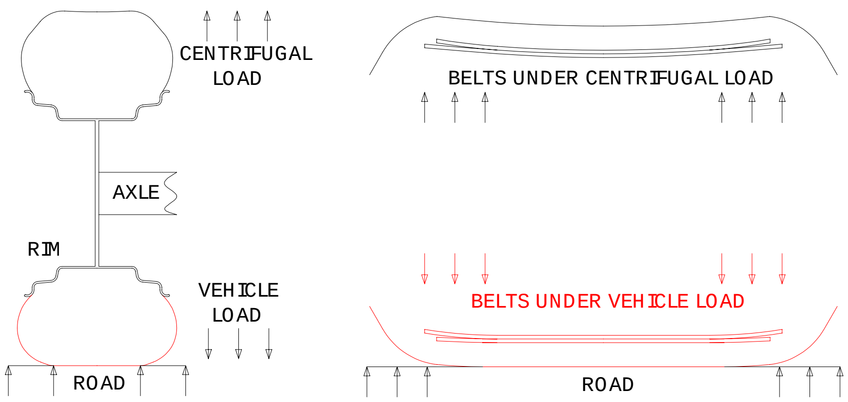
Stresses arise when the tire is loaded and run at speed on a vehicle and further stresses occur during accelerating, braking and cornering forces.

For simplicity, the stresses that are now considered are those that arise in a tire during straight-line, non-braking, non-accelerating motion.

Imagine one small section of a tire on a vehicle running at some speed

The tire is rotating so as that small section comes into contact with the road the downward load caused by the weight of the vehicle deforms it, so that the tread and the steel belts that lay under the tread deform to a near-flat shape.

The road surface causes the steel belts to be pushed INWARDS, towards the wheel axle.



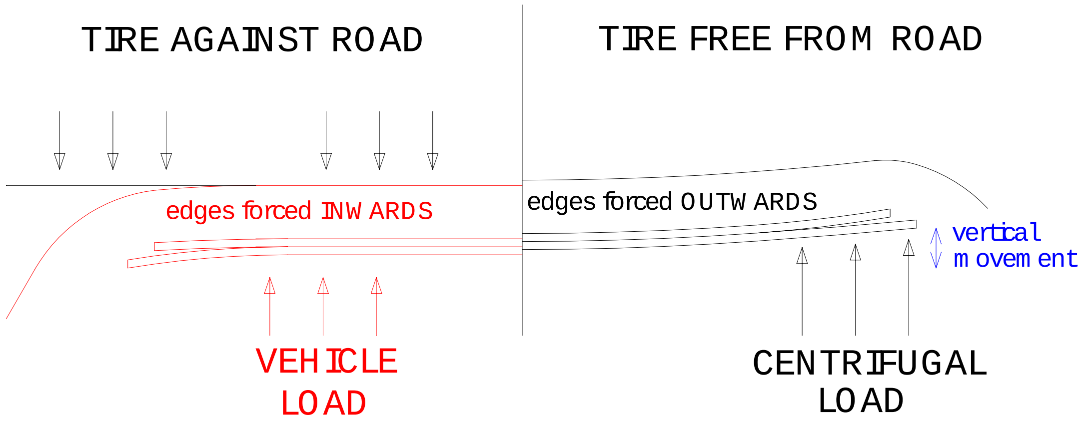
As it continues to rotate the small section passes out of contact with the road and is subject to the load exerted by the centrifugal force generated by its rotation.

The centrifugal load causes the steel belts to be pushed OUTWARDS, away from the wheel axle.

The stresses around the belt edges are further increased because the centrifugal force in the shoulder, where the belt edges are located, is greater than at the center, because the mass (weight) in the shoulder is greater than the mass (weight) in the center.

This phenomenon where the centrifugal force causes the tire to stretch and grow outwards more at the shoulder than at the center is well known in the tire industry where it known as shoulder growth.

The effect on the belt edges



The diagram shows that there is considerable movement at the belt edges during this cycle and this considerably increases the stresses around the belt edges.

The movement of the belt edges and the high stresses generated in the surrounding rubber has always presented two major problems for tire manufactures.

3. Socketing at the cut steel edges

The steel cords used in tire belts is plated with a layer of brass to promote good adhesion between the steel and rubber. However when the steel cord is cut to make the belts the thousands of cut ends at the belt edges are bare steel and have no brass plating. Consequently the bonding of the bare cut steel cord is very poor.

Because of this there are microscopic separations at the end of the cut steel cords occur with resultant looseness of the adjacent rubber. This is a well-known phenomenon and is known as socketing.

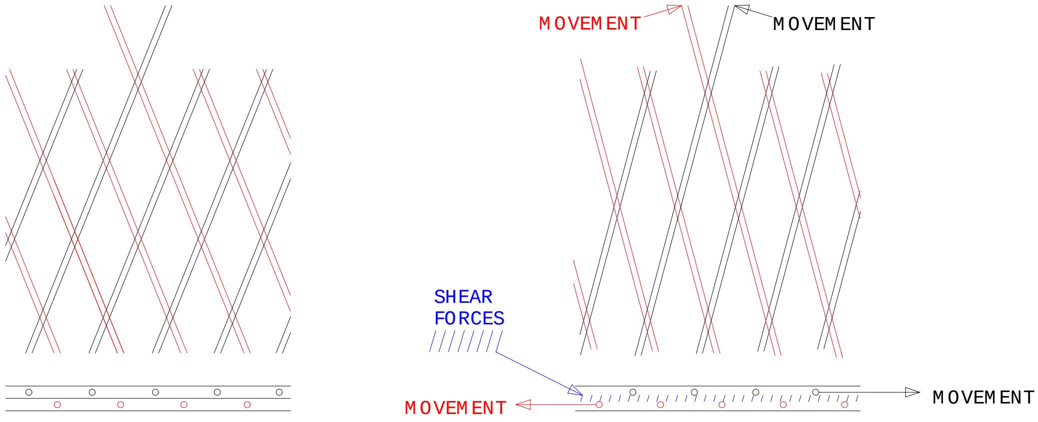
Furthermore, the thousands of cut steel ends each represent a small discontinuity in stiffness within the rubber matrix and there is a shearing action that causes fatigue of the adjacent rubber.

This is an inherent weakness in all steel belted radial tires and the socketing grows under the constant deformation of the vehicle load / centrifugal load cycle.

It is for this reason, as much as any other, that tire manufacturers concede that radial tires will eventually fail over a period of time.

4. Shearing in the rubber between the belts.

A particular effect of having the steel cords of belt #1 and belt #2 aligned in opposite directions is that as the belt package is deformed the steel cords pantograph – they are displaced in opposite directions. So as the steel cords in one belt are displaced radially in one direction, the steel cords of the other belt are displaced radially in the opposite direction.



Between the belts is a layer of rubber usually referred to as the interbelt rubber. The opposing radial movement of the steel belts causes the interbelt rubber to be distorted because the interbelt rubber attached to the top belt is pulled in the opposite direction to the interbelt rubber attached to the bottom belt.

5. Temperature build up.

Whenever rubber is mechanically deformed some of the mechanical energy is converted into heat energy and the temperature of the rubber increases.

Temperature increase in a tire is most undesirable because as rubber becomes hot it starts to age, that is, it starts to lose its physical properties.

If the temperature rises too high the rubber will revert. When rubber reverts the sulfur crosslinks that vulcanized the rubber in the first place break down and the rubber loses almost all of its physical properties (it perishes).

The increase in temperature in a tire is attributable to two factors:

a. The amount of mechanical energy that goes into the tire, which in itself is directly related to the amount of deformation of the tire.

b. The heat retention and heat dissipation properties of the tire rubber.

Summary of problems

The design and engineering problems highlighted so far are common to all steel belted radial tires irrespective of size, load or speed rating. They are by no means the only problems faced in the design and engineering of steel belted radial tires, but they are most relevant to discussion on the use of cap plies.

They may be summarized thus:

1. High stress in the rubber matrix surrounding the belt edges caused by inflation pressure.

2. High stress in the rubber matrix surrounding the belt edges caused by the vehicle load/centrifugal load

3. Stress and fatigue of the rubber in the area of socketing at the belt edges caused by the vehicle load/centrifugal load cycle.

4. Stress and fatigue of the rubber between the belts caused by shear strains.

5. Increased tire temperatures caused by the vehicle load/centrifugal load cycle.

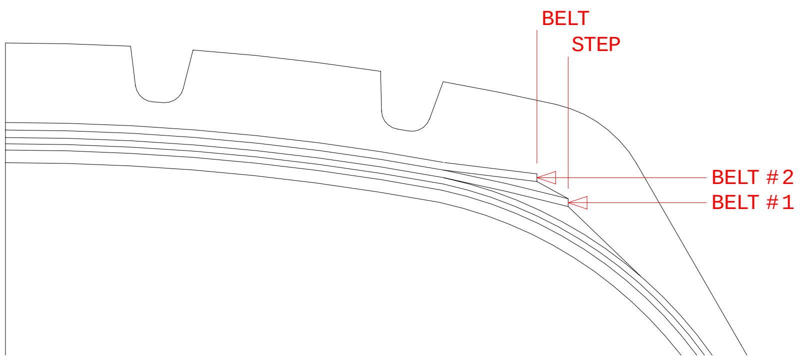
If these problems are not resolved then tire failures due mainly to fatigue of the rubber components in and around the belts is inevitable.

THE SOLUTIONS

Tire engineers traditionally use four main strategies to reduce the stresses at the belt edges and reduce tire temperatures:

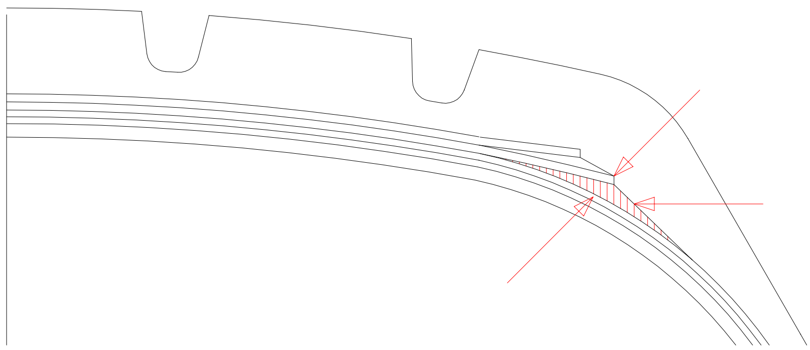
Solution #1 – belt step

The major cause of stress in the rubber around the belt edge is the discontinuity of the belt stiffness. To lessen this the belt edges are "stepped". That is, the inner belt is wider than the outer belt, so that the stiffness of the belt is gradually lessened towards the edge - the belt goes from two layers, to one layer and then zero.



Solution #2 – shoulder insert

Placing a wedge shaped rubber insert between the ply and the belt edge reduces growth of the body ply around the belt edges. This insert is alternatively called a cushion because it cushions the belt edge from the ply and helps dissipate the stresses in the area.



The shoulder insert acts as a cushion between the ply and the belt so it absorbs a lot of mechanical energy, some of which is converted to heat energy. For this reason it is important that the insert compound is formulated so that it retains as little heat as possible or, as it is known in the tire industry, it is a "cool running" compound.

Solution #3 – belt wedge and interbelt gauge

It is known that shear strains in the interbelt rubber decrease with increasing thickness between the belts and increasing stiffness of the interbelt rubber.

In the case of stiffer rubber, the reduction in shear strain is due to a reduction in the relative motion between the belts.

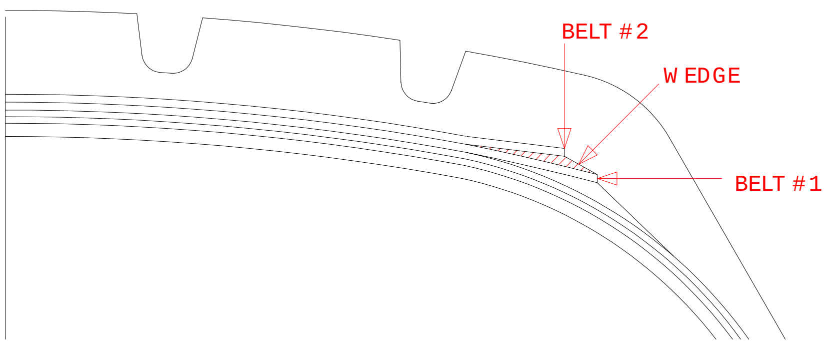
In the case of increasing rubber thickness the reduction in shear is the result of the relative motion being distributed over a larger thickness of rubber.

Therefore tire manufactures counter the effect of shearing forces between the belts by:

1. Using a stiff interbelt rubber compound to resist the relative motion of the belts.

2. Ensuring that there is sufficient interbelt rubber gauge between the belts to absorb and dissipate the stresses between the belts.

3. By placing a rubber wedge between the belt edges to act as a cushion and help absorb and dissipate the stresses in the area.

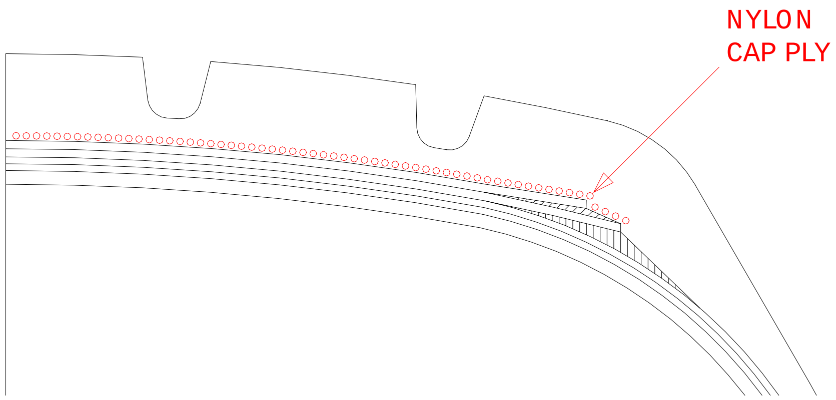


<u>Solution #4 – cap plies</u>

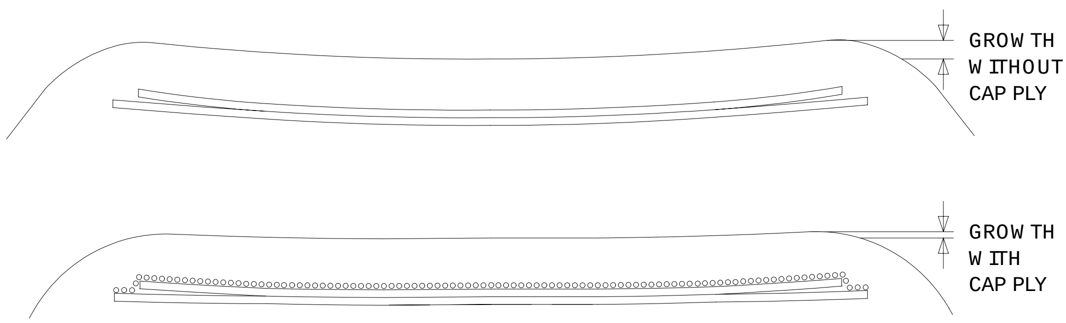
The amount of movement of the belt edge is a major contributor to the stresses in the rubber surrounding the belt edges and the generation of heat in the tire shoulder.

It has been shown that this movement occurs as a result of the vehicle load/centrifugal load cycle - cap plies are an effective means of reducing the amount of movement of the belt edge.

A cap ply is a layer of rubberized parallel nylon cords that is wrapped circumferentially over the steel belts and under the tread.



The cap ply is a mechanical device that acts a kind of tourniquet and restricts the amount of growth due to the centrifugal load on the tire:



The physical restriction of the cap ply causes the movement of the belt edge to be significantly reduced and this has three very important and significant consequences:

1. It reduces stresses and fatigue and loss of properties in the rubber surrounding the belt edges.

2. It reduces the growth of microscopic separations (sockets) that can develop into larger separations.

3. It reduces tire temperatures - heat is the enemy of tires - it weakens rubber through a process known as ageing.

The result is that tires with cap plies are more durable, less likely to fail from belt separations and therefore safer than those without.

<u>Summary of solutions.</u>

Consider this: If a tire was inflated and used as a spare then it would never fail. Therefore it is clear that the problems of high stresses at the belt edges and temperature generation arise whilst the tire is loaded and in motion.

It has been explained how a vehicle load/centrifugal load cycle deforms the belts, and in particular, the belt edges. This cycle causes the belts, and in particular the belt edges to move outwards and inwards relative to the center of the wheel.

Consider the first three solutions:

- Belt edge stepping.

- Shoulder insert.

- Belt wedge.

These solutions only respond to the problem - they do nothing to address the problem of deformation and belt edge movement due to the vehicle load / centrifugal load cycle.

The cap ply solution differs because it tackles the problem at source by reducing the movement of the belts, and in particular, the belt edges.

Discussion

The 1960's was a time of change in the tire industry. Tubeless tires were replacing tires with inner tubes and radial ply tire were replacing bias ply tires. A few manufacturers made and marketed bias-belted tires though these proved unsuccessful in the long term and died out.

It was also a time of change in the automobile industry with bigger, better and faster cars appearing and more motorways and freeways being constructed.

With the advances in automobile performance and roadways there was a demand for tires, and in particular, steel belted radial tires, that would perform at higher speeds.

This posed a problem for tire manufacturers.

At that time radial tire technology was not well advanced and making tires that performed well at high speeds was difficult for many, and impossible for some tire manufacturers. Some of the difficulties that existed then include:

- Steel cords for belts were simple and limited.
- Brass plating steel cords was a new art.
- Bonding rubber to steel cord was a new art.
- Compounds for radial tires was a new art.
- Designing moulds for radial tires was a new art.
- Calendering steel cord was a new art.
- Preparing steel cord for tires was a new art.
- Building radial tires was a new art.
- Curing radial tires was a new art.

Although most manufacturers had tire adjustment figures that were higher than would be acceptable today, performance was generally considered adequate for the service conditions of the day. But making tires that were capable of high-speed performance proved elusive for many tire manufacturers.

Tires with stepped belt edges, shoulder inserts and belt wedges had been developed but were generally found to be incapable of the required high-speed performance.

The problem was that as the tire ran faster the tire shoulders got hotter, the belt edges loosened and the two belts separated before the whole tread and belt stripped away from the carcass that very often then exploded.

Tire engineers understood the problem and in the early seventies, patents describing what are known today as cap plies started to appear.

From then on many tire manufacturers developed tires with cap plies that gave significant improvement in high-speed performance – tires that went faster for longer before failing.

However, the problem of belt edge separation was not, and is not, confined solely to high-speed tires. Belt edge separation was, and is, the single main cause of structural failure of all steel belted radial tires.

Other than high speed tires, tire manufacturers have always had some product lines more prone to belt separation than others. In particular, larger passenger and light truck tires are more prone to belt separation than small passenger tires.

Therefore, it was no great leap of the imagination to realize that the benefits derived by using cap plies in high speed tires could also be applied with the same measure of success to many of these other products.

Thus, during the 1980's and into the 1990's European tire manufacturers started using cap plies in these tire lines to increase their resistance to belt separation and in doing so making the tires more durable and safer.

Now, the situation in Europe is that the majority of steel belted radial tires are made with cap plies. Almost all light truck tires, large car tires and even many of the smaller "S" and "T" rated car tires that are made in Europe are fitted with cap plies.

Conclusion

Things have changed since cap plies were first introduced to improve high-speed performance. The whole technology of the radial tire is much better understood and the whole product much improved:

- ✓ Improved steel cord constructions are available.
- ✓ Brass plating technology is better.
- ✓ Compounds for steel cord bonding are much better.
- ✓ Mould design with CAD is better.
- ✓ Tire engineering is improved with finite element analysis.
- ✓ Tread compounds are much longer lasting.

At the same time operating conditions have become more arduous:

- ✓ Speed limits have been raised so vehicles are driven faster.
- ✓ Freeways allow vehicles to be driven for longer times; tires get hot and stay hot.

The increased demands on modern tires need to be matched by improving the tire structure and the most effective means so far discovered is by using cap plies to restrict and reduce the movement of the steel belts.

Cap plies make tires less prone to belt separation and therefore make them more durable and safer.

Many tire manufacturers have recognized this and cap plies are an integral part of the modern steel belted radial tire.

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The Role of Cap Plies - References

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