



Application Information TP-A 1

Modifiers for Wood Plastic Composites (WPC)

Background

Wood Plastic Composites (WPC) belong to a group of natural fiber-reinforced compounds in which wood fibers (or wood flour) are used as reinforcing fillers in amounts generally ranging from 50 to 80 %. A number of other natural fibers can be used for comparable applications, for example, hemp, flax, sisal, and coconut fibers. However, wood fibers are used most frequently on a volume basis. Polymeric materials such as polyethylene (PE), polypropylene (PP) and PVC are used as binders.



Advantages

WPC products are generally more expensive to produce than conventional wood materials, but have a number of advantages. Alongside much simpler forming and the variety of diversified shapes, they are more durable due to their better weather resistance. Because of their high wood content, WPC are significantly more attractive, both on a cost and technical basis, than products made of pure plastic. They are frequently used as a replacement for tropical timber on account of their longevity, thereby contributing to the preservation of ecologically important tropical forests.

Applications

Wood plastic composite materials are used wherever wood has traditionally been employed. First and foremost, WPC is employed as a flooring material (decking) mainly outdoors, but also indoors. WPC is also used as railing, privacy fencing, exterior wall cladding, furniture and much more.

Manufacture

WPC profiles, which are produced in a single or two-stage extrusion process, are the most commonly manufactured form of WPC (figure 1).

Single-stage Extrusion: This is a so-called direct extrusion process. The mixing of the wood fibers with the plastic granules (compounding) and the extrusion of the profile are performed in one step. Usually conical, counter-rotating double screw extruders are employed that are able to both thoroughly mix the wood and plastic and generate the pressure required for extruding the specified profile.

Two-stage Extrusion: In this method, compounding and extrusion of the profile occur in two separate processes. In this case, the compound can be prepared using different types of extruders. Most often parallel, co-rotating double screw extruders are used. Planetary gear extruders for the particularly gentle preparation of highly

filled compounds and heating/cooling mixer combinations are also used. Other mixing methods are pellet mills and special grinding methods in which the wood and the plastic are ground at the melting point range of the plastic. The profile is then usually produced using single-screw extruders.

If a WPC is manufactured according to the two-stage extrusion compounding process described above, it must not necessarily be extruded, but can also be further processed using other methods. Injection molding is mentioned here in particular because it is a technique that allows the manufacture of complex shapes. Other possibilities include rotational molding and the plate press method. In principle, WPC compounds can be processed by almost all conventional techniques used in plastics engineering. The limiting factor is usually the flow properties of the WPC, which are primarily determined by the wood content.

Manufacture of WPC

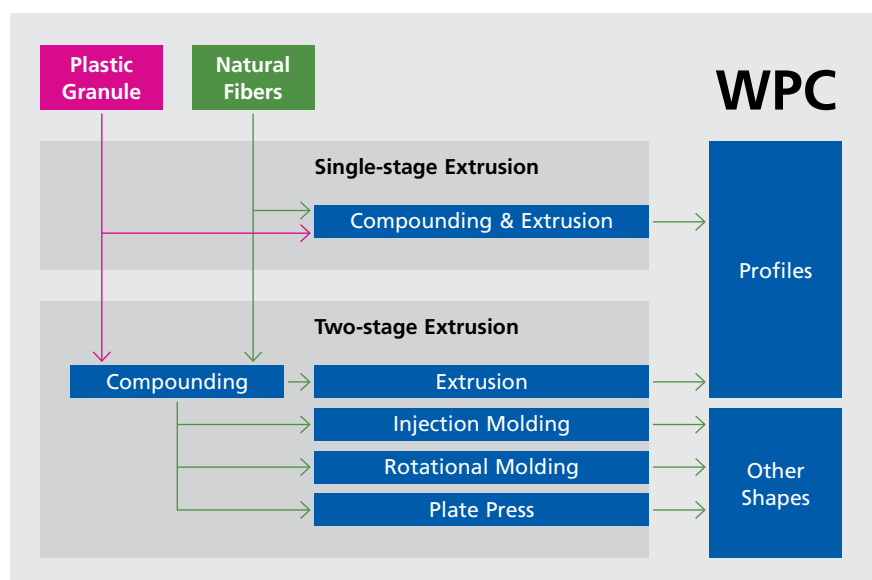


figure 1

SCONA Modifiers in WPC

In figure 2, E-modulus and Charpy impact strength values are used to illustrate the dependence of the mechanical properties of a wood flour-filled polypropylene WPC on wood content. With increasing wood content, E-modulus values increase but impact strength decreases. Whereas an increase in the E-modulus is desirable, a reduction in the impact strength is certainly not.

Through the use of SCONA coupling agents, which significantly enhance the bonding of wood fibers with the polymer matrix, mechanical properties such as bending strength and impact strength of the composite material are also greatly improved (figure 3).

Furthermore, the ability to withstand higher temperatures and surface quality are enhanced. SCONA modifiers also reduce water uptake considerably, which results in improved dimensional stability. The latter is a very important factor for outdoor applications, such as decking boards.

Chemistry of the Modifiers

SCONA modifiers are always non-polar base polymers that are functionalized with diverse monomers in a grafting process (figure 4). The modifiers used in WPC are maleic acid anhydride-modified polypropylene and polyethylene.

All SCONA products are grafted using a patented solid-phase process, whereas the standard procedure is to graft the polymers with the monomers in the melt. In solid-phase grafting, a greater degree of functionalization is achieved, resulting in a lower required concentration of modifier in the compound. The content of volatile organic compounds (VOC) is extremely low in products manufactured using this method. Moreover, the low process

Influence of Wood Content on the Mechanical Properties of a WPC

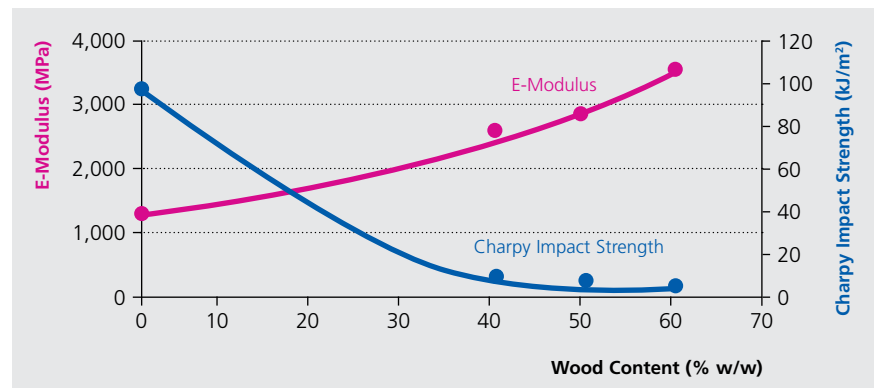
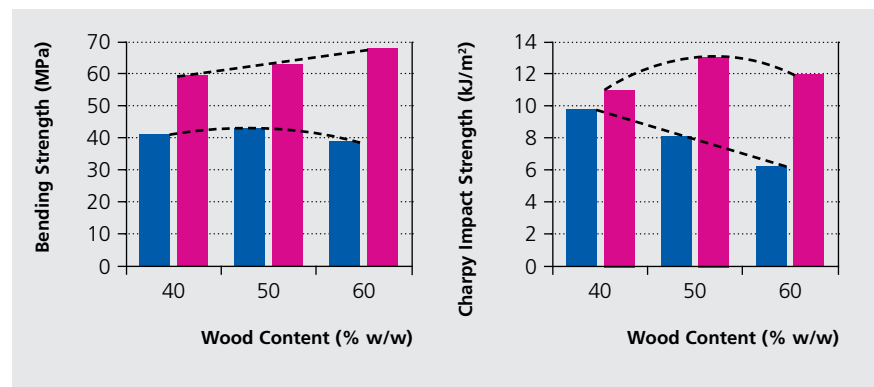


figure 2

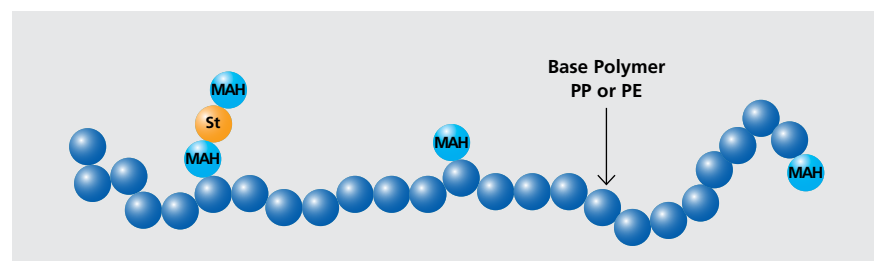
Improvement in the Mechanical Properties through Coupling Agents



■ Without Coupling Agent ■ With Coupling Agent

figure 3

Chemistry of the SCONA Coupling Agents for WPC



MAH = Maleic Acid Anhydride St = Styrene

figure 4

temperature causes less damage to the base polymer and the resulting higher molecular weight is reflected in the improved mechanical properties of the compound.

More details on the technology of the SCONA modifiers are presented in brochure TP-TI 2 "Technology of the SCONA Plastic Modifiers".

The technology also offers the possibility to graft in a two-stage process. A conventional solid-phase grafting takes place in the first stage and is followed by a melt grafting in the second stage (figure 5). Even greater degrees of grafting can be achieved by means of this combination.

"SCONA TP..." products are SCONA modifiers that are manufactured by the solid-phase process only. "SCONA TS..." products are modifiers that are manufactured by the combined process.

Combined Solid Phase Grafting and Melt Grafting

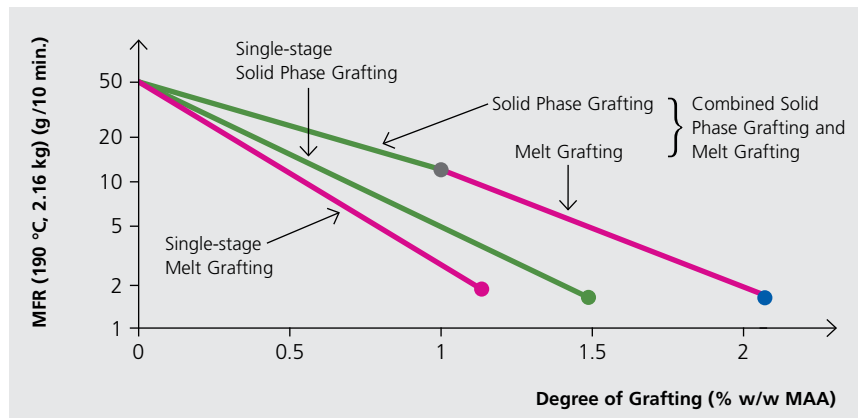


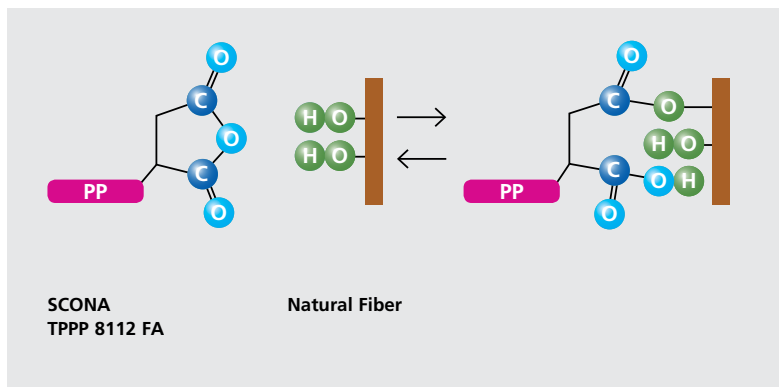
figure 5

Mechanism of Action

The maleic acid anhydride groups of the modifier react with the OH groups of the wood fibers to produce a chemically stable compound (figure 6).

As a result, the fibers are optimally incorporated into the polymer matrix, which significantly improves the mechanical properties and increases the weather resistance of the compound.

Reaction of the Coupling Agent with Natural Fibers



Incorporation of the Fibers into the Polymer Matrix

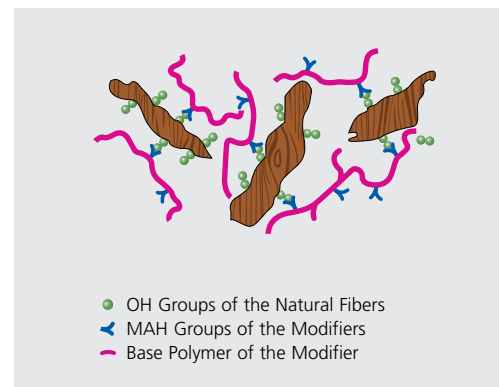


figure 6

Applications in Polypropylene

For polypropylene-based WPC, we recommend SCONA TPPP 8112 FA as the coupling agent. Figure 7 clearly shows how the mechanical properties and water uptake of a WPC is affected by the method used to manufacture the coupling agent. The values obtained using SCONA TPPP 8112 FA are uniformly better than those from a coupling agent produced by melt grafting. The values with the greatest differences are printed in red.

A comparison of several PP-based MAH-modified coupling agents was published in 2007 by Sykacek, Frech and Mundigler in the Österreichische Kunststoff-Zeitschrift (Vol. 38, 2007, 1/2, pages 12–15).

Advantages of a Coupling Agent Manufactured by Solid Phase Grafting

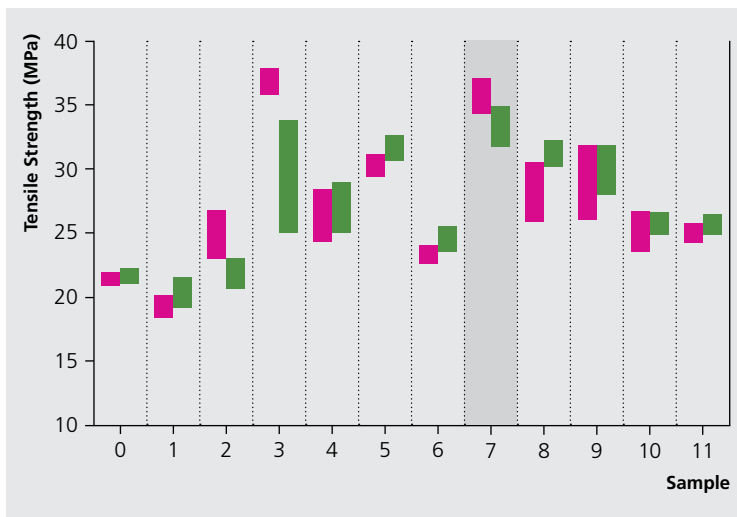
WPC with 60% Lignocel P Super (Wood Flour),
38% Polypropylene, 2% Modifier

		Modifier	
		SCONA TPPP 8112 FA	Melt Grafting
Bending Strength [MPa]	Dry	62.6	47.6
	Wet	48.1	37
Tensile Strength [MPa]	Dry	42.9	26.1
	Wet	35.1	18.6
E-Modulus [MPa]	Dry	5,040	4,820
	Wet	3,320	2,290
Charpy impact Strength [kJ/m²]	Dry	11.6	7.2
	Wet	12.3	6.7
Water Uptake [%] (After 20 days' Immersion in Water)		6.5	8.9

Source: Fraunhofer-Institut für Werkstoffmechanik in Halle, Germany

figure 7

Comparison of Several Established Coupling Agents



Tensile Strength (MPa): Mean of 5 to 6 Measurements

Sample	PP-1	PP-2	
0	21.50	21.76	Control Sample: 60% Wood Flour, 40% PP
1	19.20	20.59	
2	24.65	21.91	
3	36.56	28.12	
4	26.77	27.07	
5	30.37	31.70	
6	23.39	24.30	
7	35.91	34.07	SCONA TPPP 8112 FA
8	28.01	31.57	
9	28.78	30.25	
10	25.07	25.98	
11	25.04	25.84	Pure Polymer: 100% PP

Formulation for Samples 1 to 10: 57% Wood Flour, 40% PP, 3% Modifier

MFR (230 °C, 2.16 kg): PP-1: 40 g/10 min. PP-2: 1.5 g/10 min

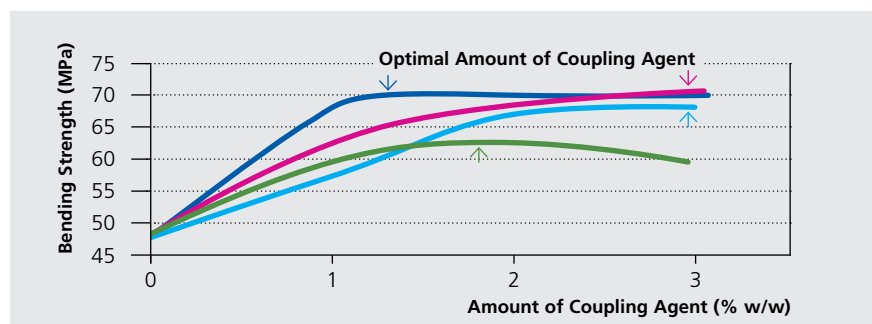
Source: IFA-Tulln Institut für Naturstofftechnik, Tulln, Austria

figure 8

Figure 8 shows some of the results and illustrates the very good performance of the SCONA product in comparison to several other established coupling agents.

Figure 9 very clearly shows again the importance of having the highest possible content of MAH in the coupling agent. The greater the degree of grafting, the less coupling agent is required for saturating the wood surface. Waxes allow significantly higher rates of grafting, but the lower molecular weight of waxes results in poorer mechanical properties.

Effect of MAH Content



WPC with PP and 40% Wood Flour

SCONA TPPP 8112FA: 1.4% MAH SCONA TPPP 9012FA: 1.0% MAH
PP with 0.5% MAH PP Wax with 7% MAH

Source: Dissertation of Klaus Specht, University of Kassel, Germany, 2007

figure 9

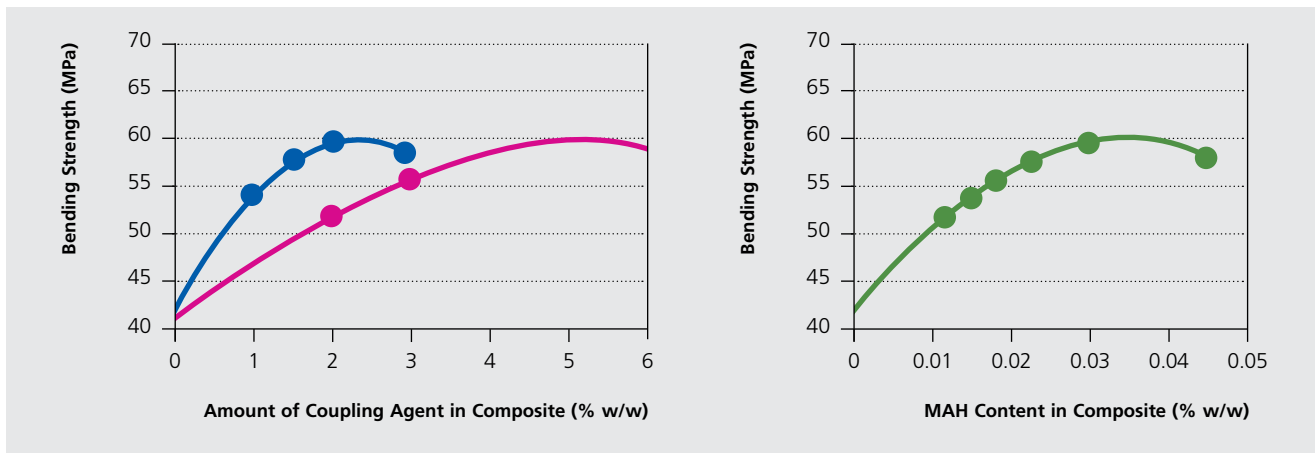
It is very important to adjust the dosage in an existing formulation when replacing a coupling agent with low MAH content for a product with a higher MAH content. Otherwise, the expected improvement in mechanical properties after the substitution may not materialize or may even result in a decline in the properties. Figure 10 illustrates this: a coupling agent with 0.74 % MAH was used at a concentration of 3 %. If the same

amount of a coupling agent with 1.72 % MAH is used instead, the bending strengths of the product are almost identical. If the amount of the latter coupling agent is reduced to 2 %, the resulting product has improved mechanical properties.

The critical factor is always the MAH content in the composite. The optimum in this case lies between 0.03 and 0.04 % MAH.

The modifier with the greater degree of grafting attains this value at a concentration of as little as 2 %, while a much higher concentration (approx. 5 %) is logically needed for the modifier with lower MAH content. The exact values vary for each specific application and with the raw materials used. Thus, it is always advisable to determine the optimal concentration by testing a series of concentrations.

Improvement in the Mechanical Properties through Coupling Agents

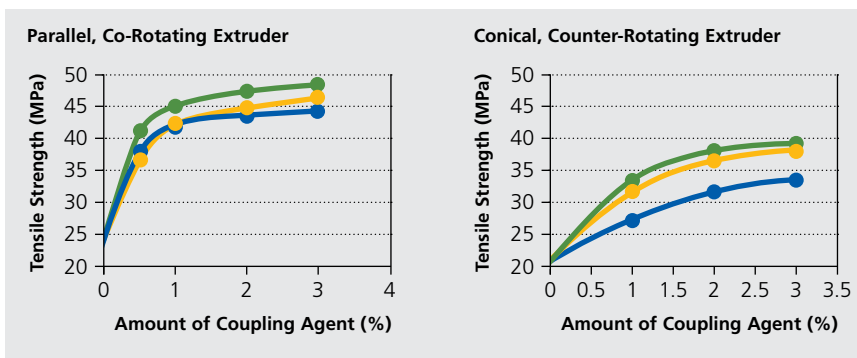


WPC with PP and 40 % Wood Flour

figure 10

■ Coupling Agent with 1.72 % MAH (Solid Phase Grafting) ■ Coupling Agent with 0.74 % MAH (Melt Grafting)

Comparison of the effect of LLDPE- and HDPE-based Coupling Agents on Mechanical Strength



■ SCONA TSPE 1112 GALL ■ SCONA TSPE 2102 GAHD
 ■ Melt-grafted Product

figure 11

Applications in Polyethylene

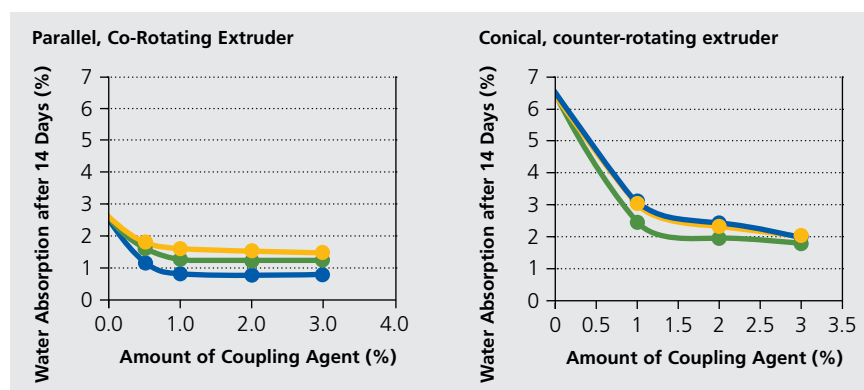
At the outset of developing WPC for wider applications in Europe, the focus was primarily on using polypropylene as the matrix material. In contrast, HDPE was the preferred matrix polymer in the USA mainly due to the wide availability of recycled HDPE from packaging material. In recent years, HDPE has also been increasingly used as matrix material in Europe in light of the better UV stability of polyethylene. However, because of the inherently lower strength and rigidity of HDPE, the use of coupling agents for improving these properties and of course, for reducing water uptake, is especially important.

Two very highly grafted SCONA modifiers that are produced through the combination of solid-phase grafting and melt grafting are extremely suitable for this application. The base polymer is either LLDPE or HDPE. Which product is used in a specific case is very dependent upon the mixing units available and the specific objectives of the respective customer (figures 11 and 12).

HDPE-based SCONA TSPE 2102 GAHD produces very good results in all systems with respect to improvement in mechanical properties and reduction of water uptake. LLDPE-based SCONA TSPE 1112 GALL is not recommended for use in mixing units that do not work the material so intensely, such as a conical counter-rotating extruder, due to the limited miscibility of HDPE and

LLDPE. In units that are able to achieve a more thorough mixing, for example a parallel, co-rotating extruder, this coupling agent does produce somewhat lower strength values (due to the lower inherent strengths), yet attains extremely good values for the reduction of water uptake.

Comparison of the Effect of LLDPE-based and HDPE-based Coupling Agents on Water Uptake



■ SCONA TSPE 1112 GALL ■ SCONA TSPE 2102 GAHD
 ■ Melt-grafted Product

figure 12

Product Recommendations for WPC

Coupling Agent for PP

	Base Polymer	Grafting	MFR (190 °C, 2.16 kg)	MAH Content
SCONA TPPP 8112 FA	PP	Solid Phase	> 80 g/10 min.	1.4 %
SCONA TSPP 10213	PP Copolymer	Solid Phase + Melt	>200 g/10 min.	>2,0 %

Coupling Agents for PE

	Base Polymer	Grafting	MFR (190 °C, 5 kg)	MAH Content
SCONA TSPE 1112 GALL	LLDPE	Solid Phase + Melt	> 5 g/10 min.	2 %
SCONA TSPE 2102 GAHD	HDPE	Solid Phase + Melt	> 5 g/10 min.	1.7 %

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