Supplementary Material (ESI) for Green Chemistry

Study of the recycling possibilities for azabis(oxazoline)-cobalt complexes as catalysts for enantioselective conjugate reduction of ethyl (*E*)-3-phenylbut-2-enoate

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Experimental

Synthesis of ligands

Ligand **1** was prepared from (*R*)-phenylglycinol and dimethylmalononitrile as described previously.[1] Ligands **2a**, **2b**, **2c**, and **4c** were prepared by methods reported by Reiser et al.[2] Ligand **5c** was prepared as previously described.[3]

Immobilization on Laponite

The chiral ligand (0.11 mmol) and the cobalt salt (0.10 mmol) were dissolved in the minimum amount of anhydrous ethanol under an argon atmosphere. The solution was stirred for 15 min. Then, a little more ethanol (4 ml in total) and laponite (375 mg), previously dried under vacuum at 140 ºC for 24 h, were added. The suspension was stirred for 24 h at room temperature. The solid was filtered off, washed with ethanol (10 ml) and dichloromethane (20 ml), and finally dried under vacuum for 24 h at room temperature.

Immobilization on Merrifield's resin

The immobilized ligands **3a** and **3c** were prepared by alkylation of the corresponding 2,2'-imino(4-substituted-4,5-dihydro-1,3-oxazole) with bromomethylated Merrifield's resin.[4,5] **3a**-C_{Me} and **3c**-C_{Me} were prepared by stirring a suspension **3a** and **3c** (0.026 mmol of ligand) in a solution of $CoCl_2$ (0.03 mmol) in the minimal required amount of anhydrous methanol at room temperature. The resulting solid was filtered, thoroughly washed with CH_2Cl_2 and dried under vacuum. **3c**-B_{Et} and **3c**-B_{THF} were prepared by the same procedure using $Co(BF_4)_2$ in anhydrous ethanol and THF respectively. After filtration and washing with the same solvent, the humid resin was used without drying.

Characterization of immobilized catalysts

Cobalt analyses were carried out by plasma emission spectroscopy on a Perkin–Elmer Plasma 40 emission spectrometer. Elemental analyses were carried out on a Perkin–Elmer 2400 elemental analyzer. Transmission FTIR spectra of self-supported wafers evacuated ($<10^{-4}$ Torr) at 50 ºC were taken with a Nicolet Avatar 360 FTIR spectrophotometer.

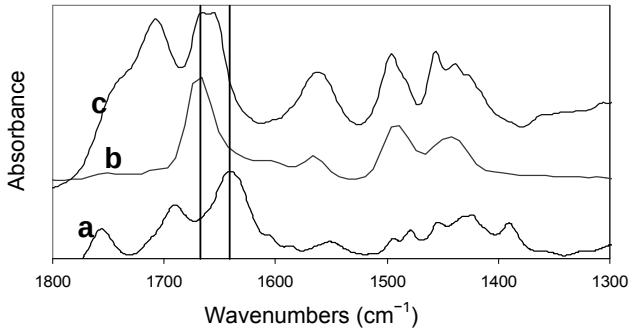

Fig. 1 FT-IR spectra of **2a**-based catalysts: a) ligand **2a**; b) **2a**-$CoCl_2$ complex; c) **2a**-Co(II)-laponite

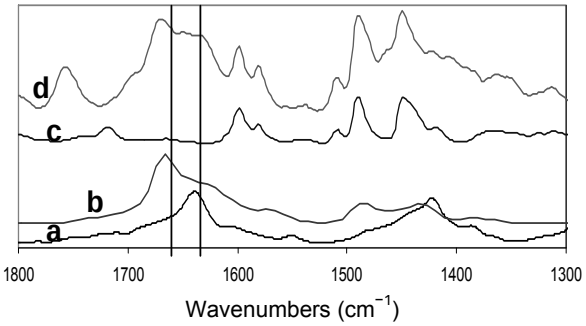

Fig. 2 IR spectra of: a) **2c**, b) **2c**-$CoCl_2$, c) brominated resin, d) **3c**-C_{Me}

Representative procedure for the homogeneous conjugated reduction of ethyl (*E*)-3-phenylbut-2-enoate[6,7]

A suspension of the corresponding ligand (0.025 mmol) and the cobalt salt (0.028 mmol) in anhydrous ethanol (1 ml) was stirred for 15 min under an inert atmosphere. After this time, a solution of ethyl (*E*)-3-phenylbut-2-enoate (1 mmol) in ethanol (1 ml) and diglyme (2 ml) was added, and the mixture was cooled to 0 ºC. $NaBH_4$ (2.5 mmol) was slowly added in portions and, after the addition was completed, the reaction mixture was stirred 24 h at room temperature under inert atmosphere. The resulting crude was diluted with H_2O (20 ml) and extracted with CH_2Cl_2 (3 × 30 ml). The combined organic layers were washed with H_2O (3 × 10 ml), dried with anhydrous $MgSO_4$ and concentrated under vacuum. The residue was purified by column chromatography (SiO_2, hexane/diethyl ether = 20/1) affording the product as a clear oil. ^{1}H-NMR and HPLC analysis of the mixture allowed the calibration of the HPLC signals in order to determine the yield in subsequent reactions. The ee was also determined by HPLC using a Chiralcel OD-H column, hexane/isopropanol 95:5 at 0.5 ml/min and a UV detector at 210 nm. Retention times: ethyl (*R*)-3-phenylbutanoate 8.6 min, ethyl (*E*)-3-phenylbut-2-enoate 9.8 min, ethyl (*S*)-3-phenylbutanoate 11.2 min.

Representative procedure for the heterogeneous conjugated reduction of ethyl (*E*)-3-phenylbut-2-enoate

To a suspension of the solid catalyst (required amount containing 2.5 mol% of cobalt) in anhydrous ethanol (1 ml) was added a solution of ethyl (*E*)-3-phenylbut-2-enoate (1 mmol) in ethanol (1 ml) and diglyme (2 ml), and the mixture was cooled to 0 ºC. $NaBH_4$ (2.5 mmol) was slowly added in portions and, after the addition was completed, the reaction mixture was stirred at room temperature under an inert atmosphere. The consumption of ethyl (*E*)-3-phenylbut-2-enoate was monitored by gas chromatography using a SPB-5 column (retention time: 11.2 min at 125ºC (5 min), 5ºC/min, 250ºC (5 min)). The mixture was filtered, and the filtrate was concentrated under vacuum. Subsequently, the residue was redissolved in water (20 ml) and extracted with CH_2Cl_2 (3 × 30 ml). The combined organic layers were washed with H_2O (3 × 10 ml), dried with anhydrous $MgSO_4$ and concentrated under vacuum. The results were analyzed by HPLC. The solid catalyst was washed repeatedly with ethanol and anhydrous dichloromethane, dried under vacuum, and reused under the same conditions.

The heterogeneous character of the reaction was tested by filtration experiments. In a reaction under standard conditions, the solid catalyst was quickly filtered off after 30 min. $NaBH_4$ (2.5 mmol) was added to the solution to ensure the presence of the reductant and the reaction mixture was stirred at room temperature under an inert atmosphere. The crude was analyzed as in the case of a homogeneous reaction. The solid catalyst was reused under the same conditions.

Notes and references

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